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THE EFFECT OF SPORT PARTICIPATION ON BONE

BY

MAGGIE M. MINETT

A dissertation submitted in partial fulfillment of the requirements for the

Doctor of Philosophy

Major in Biological Sciences

Specialization in Biology

South Dakota State University

2017

THE EFFECT OF SPORT PARTICIPATION ON BONE

MAGGIE M. MINETT

This dissertation is approved as a creditable and independent investigation by a candidate for the Doctor of Philosophy degree and is acceptable for meeting the dissertation requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Bonny L. Specker, Ph.D.
Dissertation Advisor

Date

Volker Brozel, Ph.D.
Head, Dept. of Biology & Microbiology

Date

Dean, Graduate School

Date

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LIST OF ABBREVIATIONS

- aBMD – areal bone mineral density
- BMC – bone mineral content
- CSA – cross-sectional area
- CV – coefficient of variation
- DXA – dual energy x-ray absorptiometry
- EPT – extension peak torque
- FN – femoral neck
- FPT – flexion peak torque
- H/Q – hamstring/quadriceps
- LM – lean mass
- pQCT – peripheral quantitative computed tomography
- pSSI – polar strength strain index
- SC – soccer players
- SD – standard deviation
- SE – standard error
- vBMD – volumetric bone mineral density

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ABSTRACT

THE EFFECT OF SPORT PARTICIPATION ON BONE

MAGGIE M. MINETT

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Mechanical loading – or physical activity – is essential in the bone remodeling process as well as optimizing the densitometric and geometric properties of bone throughout the lifespan. Participation in sports is a common mode of physical activity that can enhance bone mass accrual at younger ages and facilitate bone mass maintenance at older ages. Research suggests that sport participation continued from adolescence into high school and college provides added benefits on aBMD and cortical bone measures and these benefits remain 10-15 years after retirement from sport. However, in most studies, the higher rates of bone loss after sport cessation in the athlete population leads to similar aBMD measures as non-athletes by fifty to sixty years of age.

The following chapters introduce research studies that use DXA and pQCT measures during collegiate sport participation and after sport cessation to evaluate the short- and long-term effects on aBMD, cortical and trabecular bone parameters. The topics of the influence of a training season on bone and body composition of female collegiate soccer players, the response of aBMD to a range of years of retirement from collegiate soccer and football, and the comparison of DXA and pQCT measures between groups with various sport-seasons of high school and college sport participation multiple years after sport cessation are reported. Overall, participation in sport provides short-term benefits on bone; however, this benefit does not persist beyond the mid-fifties.

CHAPTER 1

INTRODUCTION

An Introduction to Bone Remodeling

When mechanical stress is placed on bone, it will undergo bending and torsional stresses caused by ground reaction forces and forces created by surrounding muscle contractions. This process is also known as mechanical loading and will result in the bone remodeling to meet the needs of these stresses. An important concept in understanding the control of bone remodeling is the role of mechanical loading and the microstrains produced in bone that promote bone formation. The extent of bone response to mechanical loads depends on the magnitude, strain rate (rate of change in deformation), and frequency of the microstrain placed on the bone. Daily activities such as walking, climbing stairs or standing produce relatively small magnitude, high-frequency strains on the bone to which necessary bone adaptations have occurred [1]. Strains measured in vivo on human tibias during walking and running are well below fracture threshold (400-850 $\mu\epsilon$) [2]. In order to induce bone formation, the magnitude of the strain or frequency of the strain needs to be great enough to induce enough deformation, yet avoiding complete failure in the bone to elicit site-specific adaptations [3]. When a load is placed on the bone such as a ground reaction force, compressive and tension stresses occur at specific sites that would elicit bone tissue adaptation to the greater strain. As microstrain increases, the deformation of the bone increases. Thus, individuals who partake in strenuous physical activities (such as sports) tend to have larger and stronger bones than sedentary individuals. During downhill, zig-zag running, microstrains in tibia increased

3-fold over those experienced during walking [4]. Greater microstrains and strain rates (such as those experienced when increasing workout loads or starting a new sport) produce greater bone deformation especially if the density or structure of the bone is not modeled to meet these demands. In this case, small amounts of microcracks or microdamage occurs. If this microdamage accrues at a slow rate and adequate time is allowed for bone tissue repair, the quality and structure of the bone tissue will be adjusted as needed without injury. Dramatic decreases in mechanical loading such as bed rest or space travel induces decreases in bone tissue as the body determines this tissue is not needed [3, 5]. Conversely, microstrains at too great of a magnitude or frequency can cause bone tissue breakdown by either increasing deformation beyond the upper limit or decreasing the necessary rest period for necessary bone formation/adaptation to occur.

Assessing the Bone Response to Mechanical Loading

When assessing the ability of a structure to withstand strain, it is imperative to assess the structural quality and architecture. The skeletal system represents a modifiable structural support system continually adapting its shape and density to better suit forces applied upon it by different types of mechanical loading – or more commonly known as physical activity and exercise. As physical activity increases, bone remodeling increases to compensate for the added mechanical stresses on the bone. Old bone is resorbed and replaced with newly modeled bone and mineralized to improve the bone tissue density and resistance to stress. Periosteal expansion also occurs to increase the bone size and resist bending forces. The structural quality – density – and architecture – geometry – can be measured using techniques known as dual x-ray absorptiometry (DXA) and peripheral

quantitative computed tomography (pQCT).

Areal bone mineral density is assessed using DXA which measures the amount of bone mineral content and bone area. The amount of mineral content within a given area will provide a measure of bone density. Decreased mineral content or mineralization will lead to less dense, weaker bones that are less well-adapted to withstand increased mechanical strains produced by physical activity. Bone geometry is also a factor in the ability of the bone to resist directional bending and torsional forces. pQCT provides unique densitometry measures separating cortical and trabecular regions as well as geometric properties of bone, which provide an indication of bone strength. Many measures are used to assess bone geometry such as cortical thickness, volumetric BMD (vBMD), cross-sectional area (CSA), cortical area, and bone strength can be calculated by the polar strength strain index (pSSI). DXA and pQCT measures provide surrogate measures of bone strength and are useful in determining factors related to bone strength, and furthermore, how those factors can be modified to optimize bone quality and structure, reduce risk of fracture, and attenuate age-related bone loss. One such example of how lifestyle factors can modify or influence densitometric and geometric properties of bone is the role of sports participation, and how this participation may have short- and long-term benefits on bone mass and size.

Sports Participation and Bone

Due to the risk of osteoporosis and osteoporosis-related fractures as well as mortality rates among fracture patients, it is important to understand factors associated with bone gain and later bone loss in life [6]. Numerous cross-sectional and longitudinal

studies have reported that participating in bone loading activities such as sports prior to and during puberty is beneficial for bone mass accrual and can have a beneficial effect on areal bone density (aBMD) [7-19]. Additionally, it appears that continued sport participation into the collegiate level has a beneficial effect on bone. Cross-sectional studies on active athletes have indicated a positive effect of collegiate sports participation on aBMD compared to non-athlete controls [15, 20-27]. Furthermore, athletes continue to improve aBMD measures throughout their collegiate career indicating an adaptation to loading over the competitive seasons [28]. As for geometric properties of bone, athlete groups have greater cortical area, thickness, and moment of inertia compared to controls [29-36].

While there have been a number of studies examining the effects of current sport participation on aBMD in many different sports, there is greater interest in this relationship between sports and bone measures after retirement from sport. With the beneficial effect of collegiate sports on aBMD and bone geometry demonstrated in previous studies, it is important to understand how this relates to positive bone changes that may continue past the athlete's career or if additional participation in collegiate athletics perpetuates the positive influence of sports on bone accrual that is seen in adolescence.

Various studies report losses of aBMD associated with sport participation cessation, but aBMD measures in former athletes are still greater than age-matched controls early after retirement [11, 13, 14, 16] although this may be site-specific [37]. Intuitively, the body responds to the decreased activity by adjusting the aBMD

accordingly – an example of the bone remodeling to meet current physical activity demands.

Many longitudinal studies have reported on whether prior physical activity levels are associated with adult bone mass, aBMD, and bone size [7-14, 38-41] with inconsistent findings. Previous physical activity has been linked to increased aBMD [18, 42] and cortical bone measures [41] while decreases in physical activity led to decreases in trabecular vBMD [41], but not always [39, 43]. However, the majority of these longitudinal studies included relatively young men which may not provide an indication of the long-term benefits of sport participation to mediate age-related bone loss. Concerning bone density measures in athletes after many years of retirement, few recent studies have suggested that sports participation during adolescence and young adulthood may have a protective effect on aBMD up to 20 years after career completion [9, 12, 16]. One study reported higher aBMD in ≥ 70 year old former athletes compared with controls [9]. This study did not demonstrate a decrease in fracture risk in the former athletes [9] while another study reported a reduction in fragility fractures in former athletes ≥ 60 years of age compared with controls [12].

Specific Aims

The following chapters present research studies that aim to use DXA and pQCT measures during collegiate sport participation and at varying years of retirement from sports to determine the effects of a high level of sport competition during young adulthood on short- and long-term aBMD, cortical and trabecular bone parameters. We hypothesize that current and former athletes will have higher aBMD and cortical bone

measures during and shortly following sport participation. Additionally, we hypothesize that former athletes will have greater rates of bone loss early in retirement and that aBMD measures will be similar to non-athlete controls with greater time since retirement.

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CHAPTER 2

CHANGES IN BODY COMPOSITION AND BONE OF FEMALE COLLEGIATE
SOCCER PLAYERS THROUGH THE COMPETITIVE SEASON AND OFF-SEASON

Maggie M. Minett, M.S.* Teresa B. Binkley, Ph.D.,* Lee A. Weidauer, Ph.D.,* Bonny L.
Specker, Ph.D.*

*EA Martin Program in Human Nutrition, South Dakota State University, Brookings,
SD, USA

ABSTRACT

Objectives: To assess body composition and bone changes pre- to post-season (pre-post) and post- to off-season (post-off) in female soccer athletes (SC).

Methods: Outcomes were assessed using DXA and pQCT in 23 SC and 17 controls at three times throughout season.

Results: SC, non-starters in particular, lost lean mass pre-post (-0.9 ± 0.2 kg, $p < 0.01$; not different from controls, $p = 0.2$) and gained fat mass post-off (1.4 ± 0.3 kg, $p < 0.01$; differed from controls, $p = 0.01$). Baseline femoral neck and hip aBMD were higher in SC than controls (both, $p < 0.04$), but increased in controls more than SC in pre-post and decreased post-off. SC cortical bone mineral content (BMC), cortical area and periosteal circumference increased pre-post (all, $p < 0.01$; differed from controls, $p < 0.05$) and trabecular vBMD decreased post-off (-3.0 ± 1.3 mg/cm³; $p = 0.02$; not different from controls, $p = 0.4$). Both SC and controls increased cortical BMC, cortical area, and thickness post-off (all, $p < 0.01$).

Conclusion: Soccer players lost lean mass over the competitive season that was not recovered during off-season. Bone size increased pre- to post-season. Female soccer

athletes experience body composition and bone geometry changes that differ depending on the time of season and on athlete's playing status. Evaluations of athletes at key times across the training season are necessary to understand changes that occur.

Keywords: Bone, athletes, female, pQCT, DXA

Introduction

Collegiate soccer athletes spend multiple hours per week meeting the physical demands of their sport. This includes time spent conditioning, strength training, practicing and competing in games throughout the season as well as continued conditioning and training throughout the off-season. Participation in collegiate athletics is known to influence multiple physiological parameters including but not limited to body composition, muscle strength, and bone characteristics [1, 2]. However, few studies have examined potential changes in these parameters over the competitive soccer season and into the off-season in female athletes [3-5].

Body composition may differ by sport due to sport-specific training and performance expectations [3]. During the off-season (end of a competitive season until the next competitive season), soccer players generally participate in a periodized strength and conditioning program designed to optimize agility, speed, aerobic and anaerobic capacities. During the competitive in-season period (typically August through November), strength and conditioning training is replaced with team training, competitions, injury rehabilitation and recovery. Some studies involving soccer athletes have reported decreases in lean mass from pre-season to post-season [3, 4] while others have reported no change or gains in lean mass over the competitive season [5-7]. However, these studies used different methods (hydrostatic weighing or dual-energy x-ray absorptiometry, DXA) to measure body composition and performed these measures at different times of the season which may explain inconsistencies among results.

Many studies assessing the effect of sport participation on bone density are cross-sectional and provide data from one time point during a competitive year. Cross-sectional

studies indicate a positive effect of collegiate sports participation on areal bone mineral density (aBMD) for total body and at regional sites in female athletes compared to non-active controls [1, 2, 8-13]. Additionally, odd-impact loading sports such as soccer and tennis appear to have a similar osteogenic effect on bone compared to high-impact loading sports such as volleyball and hurdling due to the torsional nature of cutting and turning without large ground reaction forces [13, 14]. Alfredson et al. reported significantly higher DXA measured aBMD at the lumbar spine, femoral neck (FN), humerus, distal femur, and proximal tibia in DII female soccer players compared to non-active controls [1]. Likewise, Nikander et al. reported a 19.9% higher weight-, height- and age-adjusted FN aBMD in soccer players compared to nonathletic controls [13]. While there have been a number of studies examining the effects of physical activity on aBMD in many different sports, few have investigated this relationship longitudinally in female soccer players. A study in college female athletes found significant increases in aBMD of the total body, arms and legs from the off- or pre-season to post-season indicating an adaptation to loading over the competitive season [3]; however, an odd-impact loading sport was not represented in the aforementioned study. Additionally, changes in aBMD at a regional site such as the hip were not investigated.

Peripheral quantitative computed tomography (pQCT) provides unique densitometry measures separating cortical and trabecular regions as well as geometric properties of bone, which provide an indication of bone strength. Although DXA studies have demonstrated higher aBMD measures in athletes compared to non-athlete controls, studies using pQCT measures have found lower cortical volumetric BMD (vBMD) in the athlete group compared to controls [6, 15-21]. However, these cross-sectional studies find

greater cortical area, thickness, and moment of inertia in the athlete groups demonstrating a geometric adaption to exercise [6, 15-20]. Additionally, a longitudinal study by Weidauer et al. found significant increases in bone area and cortical thickness at the 20% site of soccer players over 27-31 weeks (including the competitive and off-season periods) showing a positive adaptation to odd-impact loading over time [22].

With the beneficial effect of soccer on aBMD and bone geometry demonstrated in previous studies, it is important to understand how intense, collegiate sport participation effects the body over a season and how this relates to positive bone changes that may continue past the athlete's career or if additional participation in collegiate athletics perpetuates the positives influence of sports on bone accrual that is seen in adolescence.

The objective of this study was to test the effect of one competitive season and off-season training on lean mass and fat mass changes measured by DXA. Additionally, we investigated the changes in total hip and FN aBMD from pre- to post-season and post- to off-season as well as longitudinal changes in pQCT measures. We hypothesized that over the competitive season lean mass, total hip aBMD, FN aBMD and tibial vBMD would decrease, and tibial bone size would increase. During the off-season, we hypothesized that lean mass, aBMD and vBMD would return to pre-season levels. We further investigated whether or not changes differed by player status (starter vs. non-starter).

Materials and Methods

Subjects

The study was approved by the South Dakota State University Institutional

Review Board and written informed consent was obtained from each study participant before the study began. Subjects included 24 NCAA Division-I (D-I) female collegiate soccer players and 18 non-athlete controls. Non-athlete controls were female students recruited from campus who exercised no more than 2 days per week for a total of less than 60 minutes/week during the study time frame. Individuals who had been diagnosed with any illness or currently were taking medications known to affect bone metabolism were excluded from the study. For a secondary analysis, the soccer player group was divided into starters (n=11) and non-starters (n=13) based on their mean playing time during the competitive season (top 11 soccer players with ≥ 70 min/game were defined as starters).

Study Procedures

All study participants were asked to complete three study visits. The first visit occurred just prior to the start of the competitive season (August; pre-season). The second visit took place within one week after the completion of the competitive season (November; post-season), and the third visit after the completion of the off-season (May; off-season). Control subjects completed their study visit at the same time intervals as the soccer athletes. Time between the pre-season and post-season visit was approximately 3 months while time between the post-season and off-season visit was approximately 6 months.

Height was measured using a stadiometer (Seca Model 225, Chino, CA) to the nearest 0.5 cm and weight was measured on a digital scale (Seca Model 872, Chino, CA) to the nearest 0.1 kg. Questionnaires including a brief medical history, current health

status and medication use, activity patterns, and menstrual status were administered to each participant.

Bone measurements were obtained using two different technologies: DXA and pQCT. Hip and FN aBMD were obtained using DXA (Hologic Discovery; Software version Apex 3.3; Hologic, Inc., Bedford, MA) along with body composition measurements of fat mass, lean mass, and body fat percentage (BF%) using NHANES reference database. The coefficient of variation (CV) for DXA hip aBMD is 1.7%. In this study, the hip of the ‘kicking leg’ was measured as indicated by the participant answering the question, “Which foot do you most often use to kick a ball?” pQCT measurements of the participants’ “kicking leg” were obtained at the 4% and 20% site of the distal tibia (indicating trabecular and cortical measures, respectively) using the Stratec XCT3000 bone densitometer (Orthometrix Inc., Naples, FL) following standard operating procedures. The 20% site was chosen due to the greater amount of physiologic response to physical activity at this distal location which is why tibial stress fractures occur most often in the distal 1/3 of the tibia [23-25]. Tibia length was measured using a segmometer (Rosscraft) as the total distance between the medial tibial condyle and the medial malleolus of the tibia and used to locate image slices. A 30-line scout view was used to reference the distal end of the bone. The settings used to obtain the image were voxel size 0.4mm and 20 mm/sec scan speed. Contour Mode 2 and Peel Mode 2 were used for the analysis. The density threshold to define trabecular bone (4% slice) was 400 mg/cm³. The density threshold to define cortical bone (20% slice) was 710 mg/cm³. To define the bone edge for pSSI calculation, a density threshold of 280 mg/cm³ was used. The 4% site provided trabecular vBMD. The 20% site provided cortical BMC, cortical vBMD,

cortical thickness, cortical area and periosteal circumference. A calculated measure of bone strength, polar strength strain index (pSSI), also was obtained from this site. The CV for trabecular vBMD at the 4% site is 0.5%. The CVs for the 20% site are: cortical BMC, 0.7%; cortical vBMD, 0.4%; cortical thickness, 1.1%; cortical area, 0.8%; and periosteal circumference, 0.5%.

Strength measurements of extension (EPT) and flexion (FPT) peak torque production and hamstring/quadriceps (H/Q) ratio were obtained using isokinetic testing on a Biodex System 4 dynamometer (Biodex Medical Systems, Shirley, NY). Participants were seated with their waist strapped to the chair, the dominant leg knee was located next to the control arm fulcrum, and the participant's dominant foot was secured to the foot holder with a Velcro strap. The participant completed a series of familiarization reps prior to each test of a different speed. The procedure consisted of 5 repetitions of isokinetic knee extension and flexion at 90, 180, and 360 degree per second bouts with a one-minute rest period between velocities.

Statistics

The differences in baseline subject characteristics between groups were analyzed using *t*-tests and chi-square analysis. The differences in baseline DXA, pQCT and Biodex measures between groups were analyzed by multiple regression adjusting for baseline height, lean mass, and fat mass. To test differences in mean change in DXA, pQCT, and Biodex outcome measures, a multiple regression analysis was used. All models for DXA and pQCT bone outcomes were adjusted for baseline measures of height, bone, lean mass and fat mass. Biodex and body composition models were adjusted for concomitant baseline measure, baseline height, lean mass and fat mass.

Marginal mean change within groups was tested to determine a difference from zero. A secondary analysis was performed dividing the soccer player group into starters and non-starters based on playing time (described above). All tests were considered significant at $p < 0.05$.

Results

Pre-season to Post-season

Subject Characteristics

Unadjusted baseline characteristics are presented in Table 2.1. At the pre-season visit, control subjects were older, taller and heavier than soccer players (all, $p < 0.05$). Baseline weight, fat mass and body fat percent were lower in soccer athletes than controls (all, $p < 0.01$). Forty-four percent of controls and 46% of soccer players were currently using hormonal contraceptives ($p = 0.93$). Irregular menstrual status determined by self-report of not menstruating every 21-35 days occurred in 22% of controls and 33% of soccer players ($p = 0.43$).

Pre-season Baseline Measurements

Group differences in unadjusted and adjusted baseline outcome measures are presented in Table 2.2. None of the unadjusted DXA aBMD measures were different between groups, but total hip and FN aBMD were higher in soccer players in models adjusting for baseline height, lean mass, and fat mass ($p = 0.01$ and $p = 0.04$; respectively). Unadjusted trabecular vBMD was greater in soccer players at baseline, but this effect did not remain significant in adjusted models. There were no other differences in baseline pQCT measures between groups. Unadjusted EPT measures were not different between

groups. In the adjusted models, EPT at 90°/sec was greater in soccer players than controls. FPT measures at all speeds were greater in soccer players than controls before and after adjustments with the exception of adjusted FPT at 360°/sec. H/Q ratio at all speeds was higher in soccer players than controls but only remained different at 180°/sec in adjusted models.

Pre-season to Post-season Changes

Two individuals did not complete a post-season visit and were excluded from the outcome change analysis (soccer, n=23; control, n=17).

Body Composition: There were no differences in lean or fat mass change between soccer players and controls. However, soccer players lost lean mass (1.7%) from pre- to post-season ($p<0.01$; Figure 2.1A), but this loss of lean mass was significant only in non-starters ($-1.2 \pm 0.3\text{kg}$; $p<0.01$; data not shown).

DXA: From pre- to post-season, control subject FN and hip aBMD increased (all, $p<0.03$), while no change was observed in soccer players (Figure 2.2A & 2.2B). Mean change in FN aBMD was different between the soccer players and controls ($p=0.02$). Change in hip aBMD was not different between groups. Change in FN aBMD in non-starters and starters was different from controls ($0.002 \pm 0.008 \text{ g/cm}^2$ and $-0.005 \pm 0.01 \text{ g/cm}^2$ vs. $0.029 \pm 0.008 \text{ g/cm}^2$, respectively; both $p<0.04$) but not each other ($p=0.53$). Adding change in lean mass to the models did not alter results.

pQCT: At the 4% trabecular site, there were no differences between groups or changes in trabecular vBMD (Figure 2.3A). At the 20% cortical site, there were increases in the soccer players in cortical BMC and cortical area similar to that observed for periosteal circumference (Figure 2.3B), and the mean changes were different from

controls (all, $p \leq 0.05$). Cortical BMC and bone area increased in both starter and non-starter groups, which were different from controls (all; $p < 0.04$) but not each other (BMC, 4.2 ± 1.8 and 3.0 ± 1.4 vs. -1.3 ± 1.4 g, respectively; both $p < 0.05$; Area, 3.6 ± 1.5 and 2.5 ± 1.1 vs. -0.9 ± 1.1 mm², respectively; both $p < 0.05$). Periosteal circumference increased in the starter group (0.5 ± 0.2 mm, $p = 0.04$), which was not different from controls or non-starters ($p = 0.09$ and $p = 0.58$, respectively). There were no changes or differences between groups in cortical vBMD, thickness, and pSSI.

Strength: Control subjects increased their FPT at 180°/s ($p < 0.01$), but this change was not different from soccer players (Figure 2.4A). Soccer players increased FPT at 360°/s ($p < 0.01$), but this was not different from the control group (Figure 2.4B). Only the starter group showed an increase in FPT at 180°/s (3.7 ± 1.8 ft-lbs, $p = 0.04$) and 360°/s (5.1 ± 2.0 ft-lbs, $p = 0.01$). The increase observed in starters at 180°/s and 360°/s was not different from non-starters, but the increase at 360°/s was different from controls (-1.0 ± 1.6 ft-lbs, $p = 0.04$). The results did not change when peak torque was normalized to body weight. Change in lean mass did not explain changes in strength.

H/Q ratio increased at the 180°/s measure in controls but was not different from soccer players (Figure 2.4C). Soccer players increased H/Q ratio at 360°/s, but this was not different from controls (Figure 2.4D). Only the starter group increased H/Q ratio at 360°/s (7.5 ± 3.0 , $p = 0.01$) which was not different from non-starters (2.6 ± 2.6 , $p = 0.22$) or controls (-0.8 ± 2.4 , $p = 0.07$). Change in lean mass did not explain changes in H/Q ratio.

Post-season to Off-season

Subject Characteristics

All baseline measures that were different between groups at the pre-season visit remained different at the post-season visit except current hormonal contraceptive use. Seventy-one percent (12/17) of controls and 39% (9/23) of soccer players were using hormonal contraceptives at the post-season visit ($p < 0.05$).

Post-season Baseline Measurements

Post-season baseline measurements in each group are presented in Table 2.3. No DXA outcomes, unadjusted or adjusted, were different between groups. Trabecular vBMD was higher in the soccer player group but did not remain significant after adjusting for covariates. No other unadjusted or adjusted pQCT measures were different between groups. FPT at 360 °/sec was higher in soccer players, but this did not remain significant when adjusted for post-season baseline height, lean mass and fat mass. H/Q ratio was greater in soccer players at speeds of 180 and 360 °/sec but did not remain so after adjustments.

Post-season to Off-season Changes

One soccer player transferred and one control subject increased physical activity above the study criteria and was excluded from further analysis. Four senior soccer players did not participate in spring season training and were excluded from the post-season to off-season analysis (soccer, $n=18$; control, $n=16$).

Body Composition: There were no changes or differences between groups in lean mass. Soccer players gained fat mass ($\sim 8.0\%$), and this gain was different from controls ($p=0.01$; Figure 2.1B). Fat mass change was significant in starters (1.8 ± 0.5 kg; $p < 0.01$) and approached significance in non-starters (1.1 ± 0.6 kg; $p=0.06$) with the change in the

starter group different from the control group but not the non-starter group. There were no changes or differences between groups in lean mass.

DXA: Total hip and FN aBMD decreased in controls (both $p \leq 0.05$; Figures 2.2A & 2.2B). These mean changes were not different from the soccer players. Adding changes in lean mass or fat mass did not explain changes in aBMD. There were no significant changes aBMD in the starter and non-starter groups.

pQCT: Trabecular vBMD significantly decreased in soccer players ($p=0.02$), but this change was not different from the change in controls ($p=0.31$; Figure 2.3A). Within the soccer player group, there was no difference in change in trabecular vBMD between starters and non-starters. Change in lean mass did not affect trabecular vBMD results.

At the 20% site, cortical BMC and cortical area increased in both soccer players and controls similar to that shown for thickness (all $p < 0.01$, Figure 2.3C), and these changes were not different between groups. Additionally, cortical vBMD ($p < 0.01$) and pSSI ($p < 0.01$, Figures 2.3D & 2.3E) increased in the control group, but the change was not different from the change in the soccer players. Both the starter and non-starter groups had increases in cortical BMC and cortical area that were not different from each other or the controls (data not shown); whereas, only starters increased cortical thickness and approached a significant increase in pSSI ($p=0.07$). The mean changes in the starters were not different from non-starters or controls. Adding change in lean mass or current hormonal contraceptive use did not alter any aforementioned results.

Strength: Controls decreased FPT ($p=0.05$) at $360^\circ/\text{s}$, but the change in FPT was not different from soccer players ($p=0.25$; Figure 2.4B). There were no changes in any of the strength measures in the soccer player group. The starter group of soccer players

increased EPT at 90°/s (9.5 ± 3.2 ft-lbs; $p < 0.01$) which was different from non-starters (-1.1 ± 2.6 ft-lbs; $p = 0.01$) but not controls (1.5 ± 2.3 ft-lbs; $p = 0.09$). The mean change in EPT at 360°/s for the starter group was different from the non-starter group (5.9 ± 3.7 ft-lbs vs. -4.3 ± 2.9 ft-lbs, $p = 0.03$) and approached a significant difference from the control group (-4.2 ± 2.5 ft-lbs, $p = 0.06$). There were no differences among or between the starter and non-starter groups for FPT measures. Adding change in lean mass did not affect results.

There were no changes or differences in H/Q ratio between the soccer player and control groups (Figures 2.4C & 2.4D). However, the starter group decreased their H/Q ratio at 360°/s (-9.8 ± 4.5 , $p = 0.03$) which was different from non-starters (5.8 ± 3.6 , $p < 0.01$) but not controls. Change in lean mass did not remain in the model for H/Q ratio results.

Discussion

Throughout the entire soccer season (pre-season to off-season), the soccer players experienced significant changes in body composition, bone geometry and strength. The soccer players lost lean mass during the 3-month long competitive season and gained fat mass from the post-season to off-season measure (~6 months). This did not translate to a decrease in or increase in aBMD at any time point. However, tibia bone size increased pre-to post-season while cortical thickness increased from post-season to off-season. The decrease in lean mass during the competitive season did not result in a decrease in strength, rather, the soccer players increased FPT at the highest speed (360°/s) as well as H/Q ratio at the same speed.

Body Composition

In our study, soccer players lost significant lean mass (particularly in the non-starter group) over the competitive season while gaining fat mass over the 6-month off-season training period. Although the change in the soccer group was not different from the control group, this is a significant clinical finding which requires further investigation. While some studies have reported a maintenance or even gain of lean mass from pre- to post-season in various sports such as soccer, softball, track, swimming, basketball and volleyball [3, 5, 7, 22, 26-28]; other studies have reported losses in lean mass from pre- to post-season in basketball, rugby and soccer athletes [3, 4, 9, 29-31]. The loss of lean mass (and gain in BF%) over the competitive season seen in our study may be attributed to the change in the strength program. The soccer players participated in 3 days per week of required strength training prior to the start of the competitive season and only one day per week of strength training during the competitive season. As the loss of lean mass was only significant in non-starters, we also may attribute the lack of playing time in games as a possible contributor to the loss of lean mass. Non-starters averaged 12 minutes/game while starters averaged 77 minutes/game, which resulted in a difference of 19.5 hours of playing time over the 3-month time period. Another reason for the decrease in lean mass could be a negative energy balance, but participants were non-compliant in completing dietary questionnaires; therefore, we do not have sufficient data to test this hypothesis. Contradictory to our hypothesis, soccer players did not regain lean mass from the post-season to off-season visit but gained a significant amount of fat mass. The reasoning behind this result is difficult to ascertain as no other studies have looked at this particular time period; just after the completion of the competitive season to the end of the off-season training period (not including the 3 months of summer training just prior

to pre-season). There is approximately a 2-week period after the completion of the competitive season where the athletes were not asked to complete any mandatory strength and conditioning workouts. Otherwise, strength workouts were assigned for the holiday break (~one month) when the athletes are at home. Therefore, the amount of time allotted for a possible detraining effect to allow for significant fat gain seems improbable. The authors speculate that it may be related to a decrease in training intensity and/or volume. Even though the strength training returns to 3 days a week (as it was just before pre-season), the intensity may not be the same. Also, the team was practicing 4 days/week and competed in 18 total games during the competitive season whereas the off-season practices are 4 days/week with ~7 total games, which is a decrease in total training volume. Again, there was insufficient dietary data to analyze for its potential role in energy balance during the off-season. Future studies should include measures of training intensity to determine its role on changes in body composition throughout the competitive and off seasons.

DXA Bone Density

Our study assessed longitudinal changes in DXA measures over the competitive season and off-season of D-I female soccer players. Contradictory to our hypothesis, there were no changes in bone measures in the athletes in either the pre- to post-season or post- to off-season time frame. However, the control subjects did increase total hip and FN aBMD (with no change in total hip and FN area) over the pre- to post-season time frame, but this was not different from the soccer players. The increase in FN aBMD was the only measure different from the soccer player group. Adding change in moderate-vigorous activity and contraceptive use to the model did not change the pre-season to

post-season results in the control group. Our results differ from another study of female athletes that demonstrated softball, basketball, volleyball and track and field athletes significantly increased total body, arms and legs aBMD over the competitive season (~12 weeks). These increases indicate an adaptation to loading over the competitive season which was not seen in our study [3]. Conversely, Stanforth et al. found no change leg, arm, pelvis, spine and trunk aBMD in female soccer athletes from pre-season to post-season [32]. Soccer is an odd-impact loading sport which may yield different results compared to high- and low-impact loading sports due to sport-specific loading patterns. Although a gain in aBMD was not expected, we are pleased to see that even though soccer player group did lose lean mass, this did not correlate to a loss of aBMD.

The controls decreased FN and hip aBMD from post-season to off-season (~6 months) with none of these changes different from the soccer player group. Unfortunately, we did not have vitamin D status or calcium intake data to determine if low vitamin D status or low calcium intakes during the winter season played a factor in the bone loss seen in the controls. A study by Taaffe et al. reported an increased percent change in DXA measured spine and FN aBMD in gymnasts compared to runners, swimmers and controls over a period of 8 to 12 months. These investigators reported a greater influence on change in aBMD of a high-impact loading sport (gymnastics) than a low- (running) or active (swimming) loading sport as well as non-active controls [9]. The time between our post-season and off-season visit was approximately 6 months which provides ample time to see bone adaptations should they occur. However, another study found no change in aBMD in female soccer athletes from post-season to the following pre-season even though all other sports measured (volleyball, basketball, swimming and

track/field) demonstrated one or more changes over the same time period [32]. The only change seen in the soccer group was a 1.2% increase in leg BMD from the first-year pre-season to the third-year post-season suggesting a long-term bone adaption over the course of the athlete's career [32]. It is unknown whether it is the nature of the odd-impact loading of the sport of soccer or the type of year-round training of the sport that produces consistent measures of total hip and FN aBMD at various time points in the collegiate training environment.

pQCT Bone Density and Geometry

Over the competitive season, soccer players significantly increased cortical BMC and cortical area by 1.4%, and periosteal circumference by 0.6%, and these changes were different from controls. The increase in periosteal circumference supported our hypothesis of increased bone size over the competitive season. Our results are similar to another longitudinal study which demonstrated an increase in cortical bone area and thickness in female soccer players from the pre-season to off-season visit compared to non-active controls [22]. This increase in bone size suggests an adaptation to the increase in loading experienced during the competitive season training as well as the osteogenic type of odd-impact loading experienced in sports like soccer and tennis [14, 18, 19]. Additionally, an increase in bone size was only significant in the starter group that experienced a greater amount of playing time throughout the season. Bone will adapt to the loads placed upon it and can alter its shape based on those types of loads [33, 34]. Weidauer et al. [6] and Rantalainen et al. [18] demonstrated that different types of sports affect pQCT measured tibial geometry based on sport-specific loading. Additionally, a rather important limitation to note about this study is the use of the dominant “kicking”

leg for all pQCT measures. Although soccer athletes are expected to be proficient at utilizing both legs within the competitive environment, it has been shown that differences between the kicking leg and support leg occur in elite athletes due to the unique forces experienced by each limb during the kicking movement pattern [35]. It is unknown whether or not the changes seen in the pQCT measures of this study would be different if they had been measured in the support leg. In the soccer athletes in our study, the increase in training results in circumferential growth to resist the unfamiliar microstrains placed on the bone; however, this did not translate to an increase in calculated bone strength as measured by pSSI. Additionally, from the pre- to post-season measure, we did not see the decrease in cortical vBMD due to increased remodeling as we hypothesized. We did see a 7.5% increase in cortical BMC, attributed to a 2.6% increase in area and a 3.1% increase in thickness from the post- to off-season measure with no gain in cortical vBMD in the soccer players; however, this was not different from the control group. Again, the increase in cortical thickness was significant in the starter group only indicating a potential effect of greater playing time in competitions and perhaps, training intensity during practices. The increased cortical thickness is due to endosteal contraction and could represent the remodeling and repairing phase when the bone has the appropriate rest periods to adapt the mechanical properties by mineralizing newly formed osteoid in response to the loads experienced during the competitive season. This represents the importance of rest periods to allow the bone to make the appropriate changes to its mechanical and geometrical structure before damage; and thus injury, could occur.

Strength

Collegiate level soccer demands skill in quickness, speed, sprinting, jumping/heading, rapid acceleration and deceleration, balance and changing direction at varying speeds and intensities. These activities require the proper level of strength and power for an overall effective performance. Few studies have investigated strength in female soccer players and how it is related to changes in bone and performance measures such as kicking velocity and ball velocity while there have been studies for male counterparts [36-38]. A study by Brophy et al. demonstrated that the muscle activation and biomechanics during a soccer kick of a male versus a female differs greatly; therefore, strength performances of male and female soccer players need to be examined separately [39]. A recent study of 22 D1 female soccer players measured knee and hip torque on a Biodex isokinetic dynamometer [40]. They reported knee torque to be correlated with ball velocity (a measure used to assess kicking performance) [40]. Although this study performed pre- and post-season measures, they did not report whether or not there were strength changes over the competitive season and into the off-season. Our study found some changes in strength over the competitive season. Soccer players increased FPT at the 360°/s measure. This correlated with the increase in H/Q ratio of soccer players at the same speed measure as an increase in flexion peak torque indicates an increase in hamstring strength; thus, improving the ratio of quadriceps to hamstring strength ratio. Only the starter group, not the non-starter group, saw increases in FPT at the 180 and 360°/s measures which may indicate an effect of playing time on hamstring strength gains at higher speeds. This may be an effect of velocity-specific training suggested by Coyle et al. [41] who showed that training at lower velocities only increases strength at lower velocities (i.e. 60°/s), but training at higher velocities (180 and

300°/s) increases strength at low and high velocities. Even though the soccer players experienced a decrease in lean mass over the competitive season, this did not translate to a decrease in extension or flexion peak torque at the knee or a decrease in H/Q ratio. During the off-season, the group of starters increased extension peak torque at 90°/s (which was different from non-starters), and the change in EPT at 360°/s in starters was greater than non-starters. Additionally, the gain in H/Q ratio at the 360°/s measure that occurred in the starters over the competitive season was lost over the off-season training. This knowledge is beneficial in examining the effect of the season (both competitive and off-season) and playing status (starter or non-starter) on changes in strength which may provide valuable information for changes in performance measures, adjustments to training protocols (training at higher speeds to increase hamstring strength at sport-specific speeds) and the role of quadriceps/hamstrings ratio (H/Q) in anterior cruciate ligament (ACL) injuries in female soccer players.

Conclusion

The soccer players in this study lost lean mass over the competitive season and gained fat mass but did not recover lean mass in the off-season. Although this did not translate to a decrease in strength measures, the loss of lean mass could be a sign of a negative outcome related to overtraining or negative energy balance which should be assessed in future studies. Bone density measures did not change over the entire study timeframe; however, we did find there was an increase in periosteal circumference from pre- to post-season and cortical thickness in the off-season in soccer players. Interestingly, these geometrical changes were significant in the starter group (not the non-starter group) indicating a possible effect of playing time in competitions and perhaps,

training intensity during practices. The female soccer athlete experiences significant changes in body composition and bone geometry which differ depending on the time frame studied: the competitive season (3 months) and off-season (6 months) and on the athlete's playing status. It is important to understand that cross-sectional evaluations of these athletes may not capture the whole picture of the seasonal training effect of collegiate sports. Certain training techniques and practices may have positive or negative consequences on athlete's health that may or may not be overtly apparent (such as changes in lean mass or bone). It is important evaluate athletes at key time points across the full training season to optimize overall health and performance and decrease risk of future injury.

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TABLES

Table 2.1. Pre-season descriptive characteristics of the groups.

Variable	Controls (n=18)	Soccer Players (n=24)	p-value
Age (yr)	20 \pm 0.4	19 \pm 0.2	0.03
Height (cm)	169 \pm 1.1	165 \pm 1.3	0.04
Weight (kg)	73 \pm 2.1	64 \pm 1.5	<0.01
Body Fat (%)	29 \pm 1.0	22 \pm 0.7	<0.01
Fat Mass (kg)	22 \pm 1.3	14 \pm 0.8	<0.01
Lean Mass (kg)	50 \pm 1.0	48 \pm 0.9	0.17
Current Contraceptive Use (%)	44	46	0.93
Irregular Menstrual Status (%)	22	33	0.43

Values are unadjusted means \pm SD.

Table 2.2. Pre-season baseline DXA, pQCT and Biodex measures.

	Control	Soccer Players	p-value	Adj. p-value
Bone Measurements:	n=18	n=24		
DXA				
Hip BMC (g)	36.6 ± 1.1	37.0 ± 1.0	0.76	0.41
Hip aBMD (g/cm ²)	1.07 ± 0.0	1.13 ± 0.0	0.10	0.01
FN BMC (g)	4.9 ± 0.2	5.0 ± 0.1	0.90	0.17
FN aBMD (g/cm ²)	1.00 ± 0.0	1.02 ± 0.0	0.63	0.04
pQCT: 4% Trabecular site				
Trab vBMD (mg/cm ³)	260.5 ± 7.4	283.8 ± 5.6	0.01	0.22
pQCT: 20% Cortical Site				
vBMD (mg/cm ³)	1163.0 ± 4.7	1160.3 ± 3.3	0.62	0.59
BMC (g)	258.2 ± 6.0	256.1 ± 5.4	0.79	0.55
Bone area (mm ²)	222.2 ± 5.4	220.7 ± 4.5	0.83	0.58
Thickness (mm)	3.8 ± 0.1	4.0 ± 0.1	0.29	0.70
Periosteal circumference (mm)	70.5 ± 1.1	68.2 ± 0.9	0.11	0.31
pSSI (mm ³)	1582.2 ± 51.6	1477.9 ± 47.1	0.15	0.37
Strength Measurements:	n=18	n=23		
Biodex: Extension Peak Torque				
90 °/sec	101.9 ± 4.4	105.0 ± 3.3	0.56	0.03
180 °/sec	76.7 ± 3.5	79.2 ± 2.5	0.57	0.07
360 °/sec	51.8 ± 2.6	52.2 ± 2.2	0.91	0.26
Biodex: Flexion Peak Torque				
90 °/sec	46.5 ± 2.4	58.2 ± 2.9	<0.01	0.03
180 °/sec	36.1 ± 1.9	44.8 ± 2.0	<0.01	0.02
360 °/sec	24.8 ± 1.5	30.1 ± 1.6	0.02	0.13
Biodex: Hamstring/Quadriceps Ratio				
90 °/sec	46.0 ± 2.0	55.8 ± 2.5	<0.01	0.20
180 °/sec	47.0 ± 1.3	56.6 ± 1.9	<0.01	0.05
360 °/sec	47.8 ± 1.4	59.0 ± 2.8	<0.01	0.15

All values are expressed as unadjusted means ± SD. One baseline Biodex test in the soccer group was not used due to improper test completion. Adjusted p-value controls for baseline height, lean mass and fat mass. DXA, dual-energy x-ray absorptiometry; BMC, bone mineral content; aBMD, areal bone mineral density; FN, femoral neck; pQCT, peripheral quantitative computed tomography; vBMD, volumetric bone mineral density; pSSI, polar strength strain index

Table 2.3. Post-season baseline DXA, pQCT and Biodex measures.

	Control	Soccer Players	p-value	Adj. p-value
Bone Measurements:	n=17	n=23		
DXA				
Hip BMC (g)	37.8 ± 1.1	37.3 ± 1.1	0.75	0.78
Hip aBMD (g/cm ²)	1.09 ± 0.0	1.13 ± 0.0	0.16	0.09
FN BMC (g)	5.1 ± 0.2	5.0 ± 0.1	0.76	0.53
FN aBMD (g/cm ²)	1.03 ± 0.0	1.03 ± 0.0	0.95	0.28
pQCT: 4% Trabecular Site	n=16	n=22		
vBMD (mg/cm ³)	260.5 ± 7.4	283.8 ± 5.6	0.01	0.14
pQCT: 20% Cortical Site				
BMC (g)	257.2 ± 6.1	260.6 ± 5.8	0.70	0.95
vBMD (mg/cm ³)	1160.7 ± 4.1	1160.9 ± 3.5	0.97	0.88
Bone area (mm ²)	221.7 ± 5.6	224.3 ± 4.6	0.72	0.93
Thickness (mm)	3.7 ± 0.1	4.0 ± 0.1	0.14	0.50
Periosteal circumference (mm)	70.6 ± 1.1	68.7 ± 0.9	0.19	0.47
pSSI (mm ³)	1590.1 ± 57.9	1490.9 ± 51.6	0.21	0.47
Strength Measurements:	n=17	n=23		
Biodex: Extension Peak Torque				
90 °/sec	103.6 ± 4.5	104.8 ± 3.1	0.82	0.26
180 °/sec	79.1 ± 3.6	80.2 ± 2.4	0.81	0.13
360 °/sec	52.5 ± 3.2	51.6 ± 2.1	0.81	0.51
Biodex: Flexion Peak Torque				
90 °/sec	52.2 ± 2.9	57.9 ± 1.8	0.08	0.37
180 °/sec	41.6 ± 2.2	46.5 ± 1.8	0.09	0.56
360 °/sec	26.1 ± 1.8	31.7 ± 1.5	0.02	0.09
Biodex: Hamstring/Quadriceps Ratio				
90 °/sec	50.9 ± 2.3	55.5 ± 1.2	0.06	0.84
180 °/sec	53.0 ± 2.0	58.0 ± 1.5	0.04	0.53
360 °/sec	50.1 ± 2.4	61.4 ± 1.9	<0.01	0.12

All values are expressed as unadjusted means ± SD. Two subjects did not complete a post-season study visit. Two post-season pQCT scans were not analyzed due to scanning error. Adjusted p-value controls for baseline height, lean mass and fat mass. DXA, dual-energy x-ray absorptiometry; BMC, bone mineral content; aBMD, areal bone mineral density; FN, femoral neck; pQCT, peripheral quantitative computed tomography; vBMD, volumetric bone mineral density; pSSI, polar strength strain index.

FIGURES

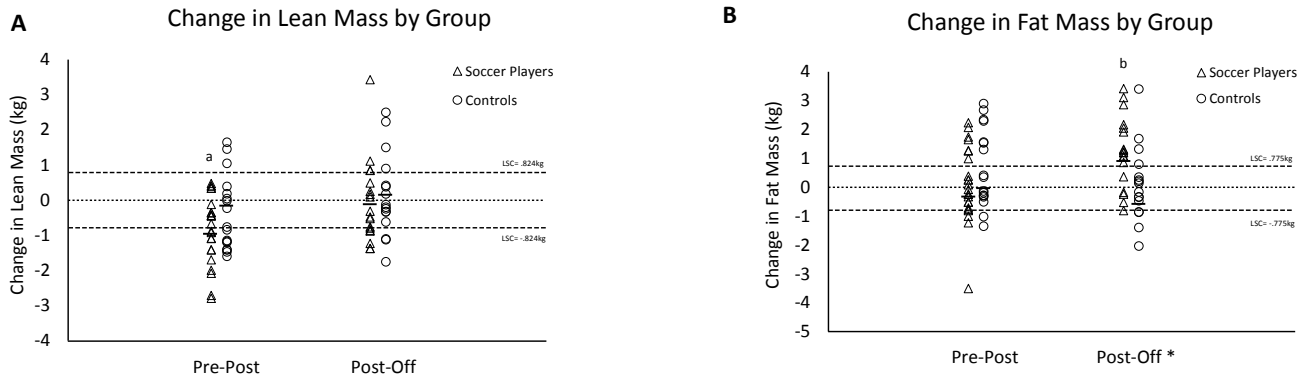


Figure 2.1 DXA measured changes in lean mass (Panel A) and fat mass (Panel B) from pre- to post-season and from post- to off-season by group. The letter *a* indicates a significant change in the group mean from pre- to post-season, while the letter *b* indicates a significant change in the group mean from post- to off-season. LSC = least significant change. Horizontal lines are adjusted group marginal mean changes. *There was a significant difference in fat mass mean change between the soccer players and the control group from post- to off-season ($p \leq 0.05$).

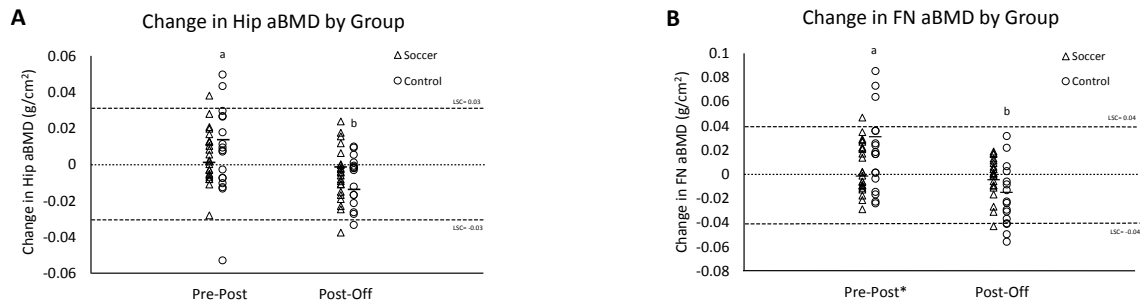


Figure 2.2. Changes in total hip (Panel A) and femoral neck aBMD (Panel B) from pre- to post-season and from post- to off-season by group. The letter *a* indicates a significant change in the group mean from pre- to post-season, while the letter *b* indicates a significant change in the group mean from post- to off-season. Horizontal lines are adjusted group marginal mean changes. LSC = least significant change. *There was a significant difference in the FN aBMD mean change between the soccer players and the control group from pre- to post-season ($p < 0.05$).

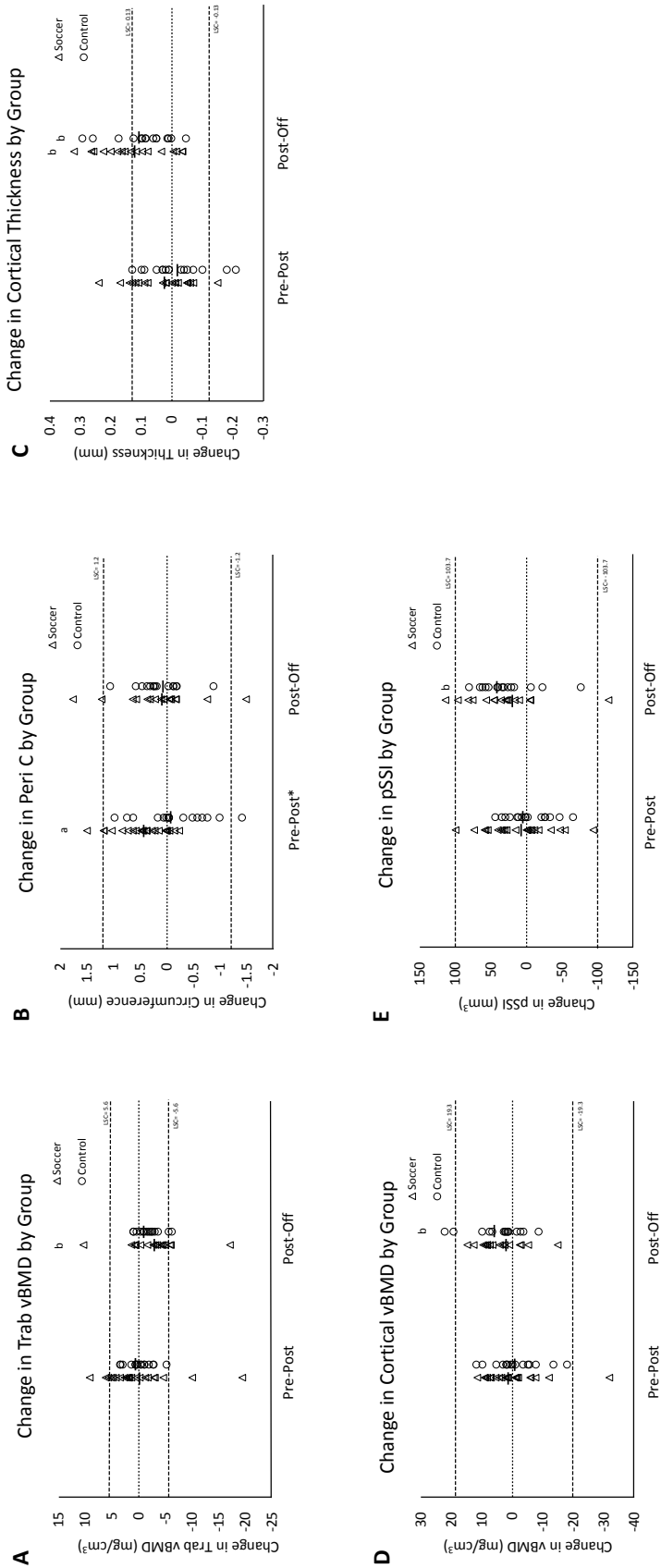


Figure 2.3. Changes in trabecular vBMD (Trab vBMD, Panel A), periosteal circumference (Peri C, Panel B), cortical thickness (Panel C), cortical vBMD (Panel D), and pSSI (Panel E) from pre- to post-season and from post- to off-season by group. The letter *a* indicates a significant change in the group mean from pre- to post-season, while the letter *b* indicates a significant change in the group mean from post- to off-season. Horizontal lines are adjusted group marginal mean changes. LSC = least significant change. *There was a significant difference in periosteal circumference mean change between the soccer player group and the control group from pre- to post-season ($p < 0.05$).

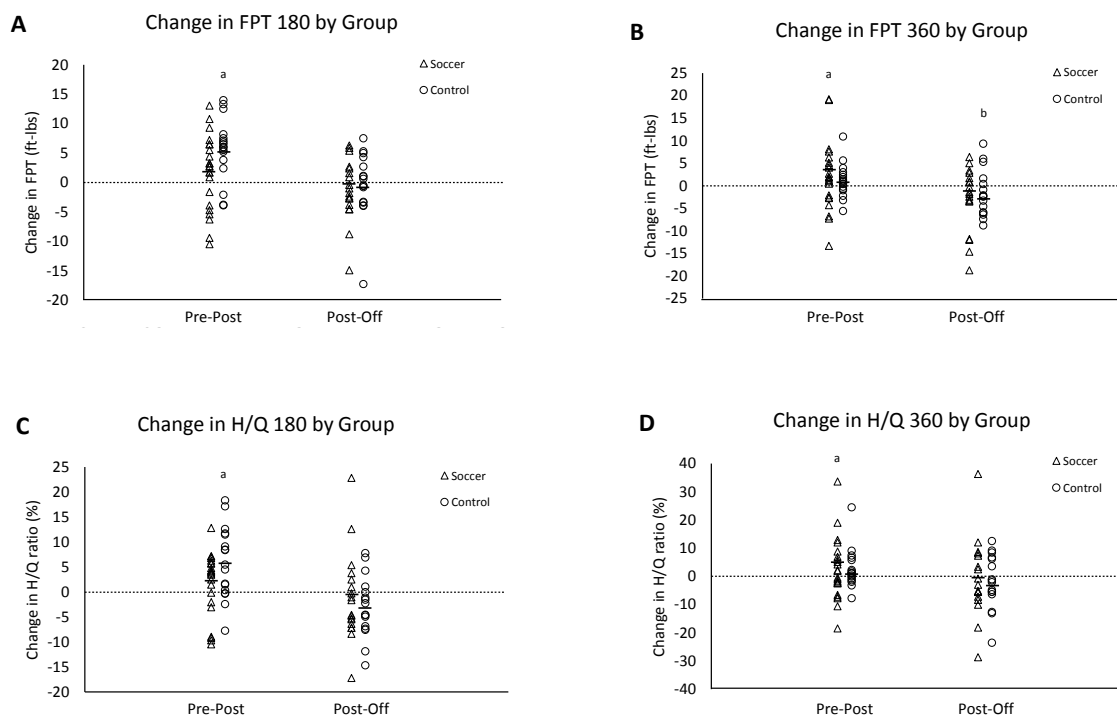


Figure 2.4. Changes in peak torque at 180°/s (FPT 180, Panel A), peak torque at 360°/s (FPT 360, Panel B), hamstring/quadiceps ratio at 180°/s (H/Q 180, Panel C), and hamstring/quadiceps ratio at 360°/s (H/Q 360, Panel D) from pre- to post-season and from post- to off-season by group. The letter *a* indicates a significant change in the group mean from pre- to post-season, while the letter *b* indicates a significant change in the group mean from post- to off-season. Horizontal lines are adjusted group marginal mean changes. Least significant changes for Biodex measurements are not available.

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CHAPTER 3
BONE MINERAL DENSITY IN FORMER MALE AND FEMALE ATHLETES
AFTER SPORT CAREER CESSATION

Maggie M. Minett, M.S.,* Teresa B. Binkley, Ph.D.,* Lee A. Weidauer, Ph.D.,* Bonny
L. Specker, Ph.D.*

*EA Martin Program in Human Nutrition, South Dakota State University, Brookings,
SD, USA

ABSTRACT

Objectives: To use DXA measures at varying years of retirement to determine the effects of retirement from a high level of sport competition during young adulthood on bone parameters.

Methods: DXA measures were obtained on former female soccer players (n=17) and male football athletes (n=18) along with age- and sex-matched controls who did not participate in varsity collegiate athletics.

Results: Former male athletes had higher spine aBMD and z-scores than non-athlete controls. In females, total hip and spine BMC, aBMD and z-score and FN BMC measures were higher in former athletes than non-athlete controls.

Conclusion: American football players may maintain higher spine aBMD than non-athlete controls for up to 15 years after retirement while former female soccer players maintained higher spine and total hip aBMD and spine, hip and femoral neck BMC than controls after 5 years of retirement from collegiate athletics regardless of current physical activity.

Keywords: aBMD, DXA, former athletes, sports participation

Introduction

Many studies have reported that odd- and high-impact loading activities during adolescence are beneficial for bone mass accrual, areal bone mineral density (aBMD) and bone size [1-9]. However, there are inconsistent findings among studies investigating the benefits of early life sport participation on bone once the athlete completes their career or reduces exercise. Some recent studies have suggested that sports participation during adolescence and young adulthood may have a protective effect on aBMD up to 20 years after career completion [3, 6, 10]. These studies also reported losses of aBMD associated with sport participation cessation, but aBMD measures in former athletes is still greater than age-matched controls [5, 7, 8, 10] although this may be site-specific [11]. One study reported 6.5% higher aBMD in ≥ 70 year old former male soccer players compared with controls, but this did not translate into a reduced fracture risk [3]. This result contradicts a study that found a reduction in fragility fractures and radial fractures in former athletes ≥ 60 years of age compared with controls [6]. The incongruity with these studies may be due to the heterogeneity of study designs involving different sports (loading patterns), sport competition level, years of retirement, sex, and bone sites that were measured. The current study aims to use DXA measures at varying years of retirement to determine the effects of retirement from a high level of sport competition during young adulthood on bone parameters. We hypothesize that former athletes will have higher aBMD measures early in retirement and that aBMD measures will be lower with greater time since retirement.

Materials and Methods

Subjects

The study was approved by the South Dakota State University (SDSU) Institutional Review Board and written informed consent was obtained from each participant. Former athlete participants were volunteers recruited from the SDSU soccer (females) and American football (males) varsity athletic teams during their yearly alumni events. The former soccer players consisted of 17 females ranging in ages of 23-31 with 2-10 years since completion of their collegiate career (average 3.9 ± 0.8 years of participation), while 18 football former athletes were males aged 24-68 with 1-46 years since retirement from varsity athletics (average 4.8 ± 0.4 years of participation). Controls subjects were age- and sex-matched individuals who did not participate in varsity collegiate athletics. The control subjects, 17 females (6 rural) and 18 males (10 rural), were participants from the South Dakota Rural Bone Health Study described in greater detail elsewhere [1]. Age was matched within 1 year.

Study Procedures

Height without shoes was measured using a Seca stadiometer (Model 225, Chino, CA). Height was measured in duplicate and if the measurements differed by more than 0.5 cm, the measurement was repeated. Weight with light clothing was measured on a Seca scale (Model 872, Chino, CA) to the nearest 0.1 kg. Information obtained via questionnaire consisted of a brief medical history, current health status, medication use, dairy intake and nutritional supplements, smoking status, alcohol intake, and coffee consumption. Estrogen status of females was determined from information obtained by questioning the individuals. Information was obtained on the use of oral contraceptives, type of oral contraceptive used, length of usage, and the approximate number of menstrual cycles in the past year. Individuals who had been diagnosed with any illness

(hyper/hypoparathyroidism, major gastrointestinal disease, liver disease, etc.) or currently were taking medications (long-term steroids, immunosuppressant therapy, long-term anticonvulsant therapy, etc.) known to affect bone metabolism were excluded from the study. Former athletes were asked about their collegiate sport career such as type of sport, length of collegiate career, average hours of exercise per week during their collegiate career, and year of completion. All participants were asked about their current physical activity (7-day recall) patterns per week and job status.

Bone measurements were obtained on a mobile research unit using dual energy x-ray absorptiometry (DXA). The use of DXA technology allowed us to measure bone mineral content (BMC) and aBMD of the total body, lumbar spine, and left hip. The Hologic Discovery (Hologic, Inc., Bedford, MA), a multiple detector fan beam DXA, can measure total body BMC, lean and fat mass, as well as regional analysis (spine and hip aBMD), and aBMD Z-scores were obtained from the manufacturer's software (Apex 3.3). CVs at our institution (based on triplicate scans from 10 adults with repositioning but without using the compare analysis option) for spine and hip BMC are 1.5% and 2.1%, respectively. CVs for spine and hip bone area are 1.1% and 1.7%, respectively. The CV for spine aBMD is 0.9% and hip aBMD is 1.7%.

Strength measurements were obtained by a handheld dynamometer (GRIP-D, Takei Scientific Instruments Co.; Tokyo, Japan) and recorded to the nearest 0.1 kg.

Statistics

Analyses were completed using JMP software (JMP Pro v10.0; SAS Institute, Cary, NC, USA). Subjects were divided into two groups based on collegiate sport participation: former athlete and non-athlete control, and analyses were stratified by sex.

Outcome measures were spine, total hip, and femoral neck area, BMC, aBMD and z-score. Student's *t*-tests were used to determine differences in the outcome measures between groups. In addition, regression analysis was used to test for differences in mean outcome measures between groups while controlling for age, height, weight, and current physical activity. Weight was used in the analyses instead of fat mass and lean mass due to DXA equipment malfunction during whole body imaging, which resulted in only 11 of the 18 males athletes having fat and lean mass measurements. Due to the high correlation between years since retirement and age, age was used in regression models as the covariate rather than years of retirement. A *p* value ≤ 0.05 was considered significant.

Results

Male Former Athletes vs. Non-athlete Controls

Characteristics of the two groups are presented in Table 3.1. Former athletes were taller and currently spent less time in moderate plus vigorous activity than non-athlete controls. Percent body fat and grip strength approached a significant difference between groups. Age, weight, BMI, lean mass and fat mass were not different between groups. There were no age-by-group interactions for any DXA outcome measures indicating that the relationships between bone outcomes and age were similar between groups. Former athletes had higher spine aBMD and z-scores than non-athlete controls (Figure 3.1) and this difference was similar across all ages. Spine bone area and BMC were not different between groups (least square means \pm SE for non-athlete controls and former athletes: area, 72.4 ± 1.5 vs. 72.5 ± 1.5 cm, $p=0.9$ and BMC, 79.1 ± 3.5 vs. 89.2 ± 3.6 g, $p=0.08$; respectively). For total hip and femoral neck, there were no differences between non-

athlete controls and former athletes in bone area, BMC, aBMD or aBMD z-scores (Table 3.2).

Female Former Athletes vs. Non-athlete Controls

Baseline characteristics of the two groups are presented in Table 3.1. Former athletes had less fat mass, percent body fat, spent less time in moderate plus vigorous activity, and had higher percentage of self-reported irregular menstrual status than non-athlete controls. Age, height, weight, BMI, lean mass, and grip strength were not different between groups. Spine bone area, BMC, aBMD and aBMD z-score measures were higher in former athletes than non-athlete controls (Figure 3.2). For total hip bone area, there was an age-by-group interaction suggesting that the relationship between hip area and age were not similar between groups. The calculated hip area using the regression model in younger ages is higher in the former athletes by 0.17cm^2 whereas at an older ages, the calculated hip area is higher in the controls than former athletes by 0.5cm^2 (data not shown). Total hip BMC, aBMD, and aBMD z-scores measures and femoral neck bone area and BMC were higher in former athletes than non-athlete controls (Figure 3.3). Femoral neck aBMD and z-scores were not different by group.

Discussion

For the former American football male athletes, spine aBMD and aBMD z-scores were higher than the age-matched controls before and after controlling for height, weight and current physical activity. For the females, BMC at all three bone sites (spine, femoral neck, hip), bone area at the femoral neck and spine, and aBMD and aBMD Z-scores at

the spine and total hip were higher in former athletes than age-matched controls before and after controlling for current physical activity. These results are consistent with our hypothesis that former athletes would have higher aBMD measures than the non-athlete controls early in retirement.

For the male athletes, the mean time since active career cessation was 15.7 years (range: 1-46; median: 11 years). Spine aBMD was the only measure that was higher in former football athletes than controls. Total hip and femoral neck measures were not different, and the relationship between these bone measures and age was not different between groups. Other studies have reported greater measures of femoral neck and total hip aBMD after retirement in former male badminton, ice hockey, and soccer athletes compared to controls [6, 7, 12]; however, these study's final follow-up visits were approximately 5-6 years after retirement. A study by Karlsson et al. in 2000 suggested that the decrease in leg aBMD over time is greater in former athletes than controls; therefore, by the time former athletes had been retired for 16-25 years, there was no difference in leg aBMD between former athletes and controls [3]. The higher spine aBMD seen in the former football players of the present study may be indicative of the type of loading and training environment experienced within the sport. Tervo et al. 2010 [12] demonstrated that although badminton and ice hockey players lost femoral neck and spine aBMD after career cessation, only badminton players maintained femoral neck and spine aBMD higher than controls while former ice hockey players did not. Similarly, male soccer players have been shown to maintain leg aBMD measures higher than controls for up to 16 years after career cessation [3] while other sports such as ice hockey do not [13].

Similar to other studies, the former female soccer athletes were closer to playing age than the males in this study and presented with higher spine and hip aBMD and femoral neck BMC than controls after retirement (median of 6 years, range: 2-10 years) [3, 5, 12, 14, 15]. Collegiate sports participation appears to have a beneficial effect on aBMD (in both males and females) in the short term that is attenuated later in life although this appears to vary by the type of sport an individual participated in [3, 6, 10]. This suggests that the type of loading experienced within the sport training may have a greater effect on the residual benefits of the sport, which is an important consideration when assessing fracture risk later in life in former athletes compared to controls. Although Karlsson et al. 2000 [3] found an increased residual benefit in former soccer players up to 20 years from retirement, this did not translate to a decreased proportion of fragility fractures in those ≥ 60 years old [3]. This conflicts with another study involving former soccer and ice hockey players that showed a significantly lower rate of fragility fractures in former athletes aged ≥ 50 years old than controls, especially at the distal radius [6]. Perhaps not only the length of time spent active in sports, but also, the type of sport needs to be taken into consideration when assessing whether or not sport participation could reduce later fracture risk. Additionally, even though there appears to be a residual effect of higher aBMD measures associated with collegiate sport participation in both males and females compared to non-athletes (and controlling for current physical activity), this may only last for 15-20 years which ends well before the age at which fragility fractures are of highest concern. Regular skeletal loading must be maintained to attenuate bone loss as demonstrated by Snow et al. 2000 [16] who was able to maintain or increase hip aBMD measures in postmenopausal women (65-70 years old)

using weighted vest exercises over a period of 5 years. However, Winters et al. 2000 [17] showed that once this activity ceased, the higher aBMD measures returned to baseline after about 6 months. Perhaps, the question should not be, how long did the individual participate in athletics throughout adolescence and young adulthood (certainly these are proven to be beneficial), but rather, what type of exercise is best for an individual to continue throughout life to best maintain aBMD and reduce fragility fracture risk?

There are some key limitations to this study. Due to a smaller sample size, there may not be enough power to detect differences in bone outcomes. This is evident with FN aBMD and FN z-score between the female former athlete group and control group where the difference is not significant but is trending in the direction that we hypothesized with p-values approaching significance (0.09 and 0.08). Ideally, a larger sample size (~85 participants) would allow us to investigate with enough power whether or not these measures are different. Repeated measures over a longitudinal time frame would have provided a clearer picture of how aBMD measures responded to the detraining experienced after collegiate sport retirement. With this, we would have been able to calculate rates of change. However, the soccer program is relatively new at the university and thus, the female alumni are relatively young with a shorter retirement period compared to the retired male athlete group. Additionally, the study did not provide accurate fracture data. Although questions about fracture occurrence after sport cessation were asked, these were not verified with radiographic or medical report evidence and therefore, not utilized as valid data. In the former American football players, this information would have been especially useful at assessing fracture risk since some of the participants were in their late 50's and 60's.

Our results suggest that former American football players may maintain higher spine aBMD than non-athlete controls for up to 15 years after retirement while former female soccer players maintained higher spine and total hip aBMD and spine, hip and femoral neck BMC than controls after 5 years. The results may be based on the type of loading (high- or odd-impact or high-magnitude) that occurs within the sport and its training environment.

TABLES

Table 3.1. Characteristics of Male and Female Former Athletes and Controls

	MALES			FEMALES		
	Controls (N=18)	Former Athletes (N=18)	P value	Controls (N=17)	Former Athletes (N=17)	P value
Baseline Characteristics						
Age (y)*	38.2 (13.1)	37.8 (13.4)	NS	26.3 (2.8)	26.2 (2.8)	NS
Height (cm)	176.3 (7.8)	183.2 (7.9)	0.01	166.6 (5.9)	165.5 (5.8)	NS
Weight (kg)	93.2 (14.4)	98.7 (22.6)	NS	70.9 (13.0)	65.5 (5.8)	NS
BMI	30.0 (4.8)	29.2 (5.1)	NS	25.5 (4.0)	23.9 (2.3)	NS
Lean Mass (kg)**	68.9 (9.1)	77.7 (14.8)	NS	45.8 (6.4)	46.4 (3.7)	NS
Fat Mass (kg)**	21.9 (7.7)	19.5 (13.8)	NS	23.3 (7.3)	17.0 (4.2)	<0.01
% Body Fat	22.9 (5.6)	18.0 (7.6)	0.06	32.1 (4.7)	25.6 (4.9)	<0.01
Grip Strength	54.3 (11.3)	61.9 (11.8)	0.06	30.6 (8.2)	34.8 (4.0)	NS
Current % Time in Mod+Vig	26.0 (12.1)	13.5 (10.7)	<0.01	21.9 (16.2)	12.1 (9.2)	0.04
Menstrual Status [†] (% regular)				94.1	47.1	<0.01
Years from sport completion		16 (range: 1-46; median: 11)			5 (range: 2-10; median: 6)	

Data are mean (\pm SD).

* Male median age for controls is 33.6 years and former athletes, 33.0 years old.

**Only 11 male athletes had lean mass and fat mass measures.

[†] Menstrual status at any point in time during or after sport career.

Table 3.2. Total Hip and Femoral Neck Results for Male Former Athletes and Non-athlete Controls

	Former Athletes (N=18)	Controls (N=18)	P value
Total Hip			
Area	46.4 ± 1.0	45.6 ± 0.9	0.6
BMC	55.0 ± 2.1	51.5 ± 2.0	0.3
aBMD	1.18 ± 0.03	1.13 ± 0.03	0.3
Z-score	0.9 ± 0.2	0.4 ± 0.2	0.2
Femoral Neck			
Area	6.0 ± 0.1	5.9 ± 0.1	0.8
BMC	6.0 ± 0.2	5.5 ± 0.2	0.1
aBMD	1.01 ± 0.03	0.93 ± 0.03	0.1
Z-score	1.1 ± 0.2	0.8 ± 0.2	0.4

Data are mean (±SD). BMC, bone mineral content; aBMD, areal bone mineral density

FIGURES

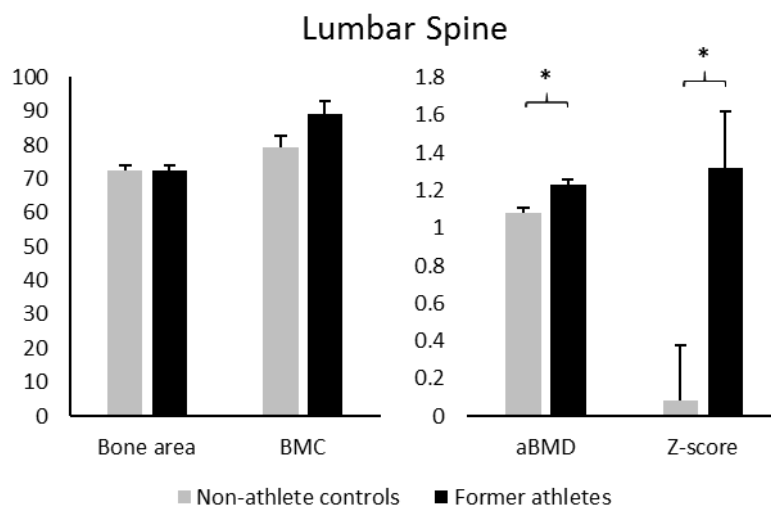


Figure 3.1. Spine bone area, BMC, aBMD, and z-score least square means (SE) for male former athletes (black bar) and non-athlete controls (gray bar). Data are adjusting for age, weight, height, and current physical activity. *Indicates a significant difference between groups ($p < 0.05$).

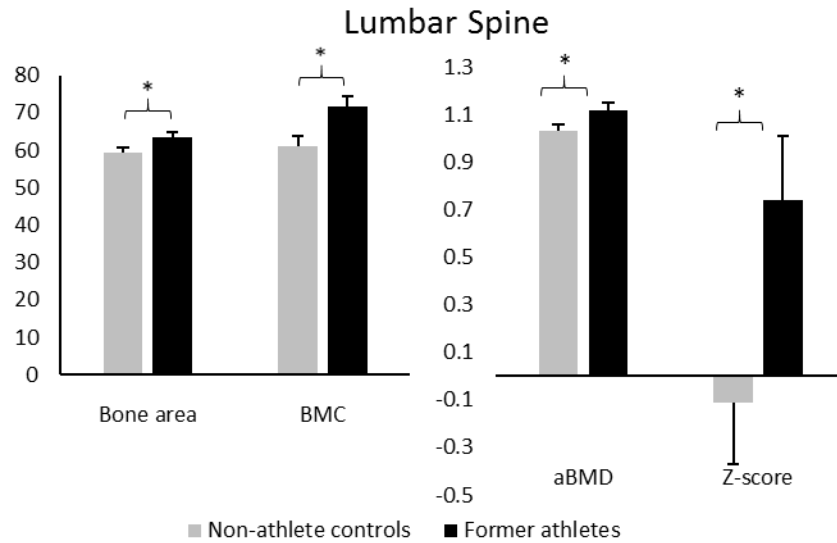


Figure 3.2. Spine bone area, BMC, aBMD, and z-score least square means for female former athletes (black bar) and non-athlete controls (gray bar). Data are adjusting for age, weight, height, and current physical activity. *Indicates a significant difference between groups ($p < 0.05$).

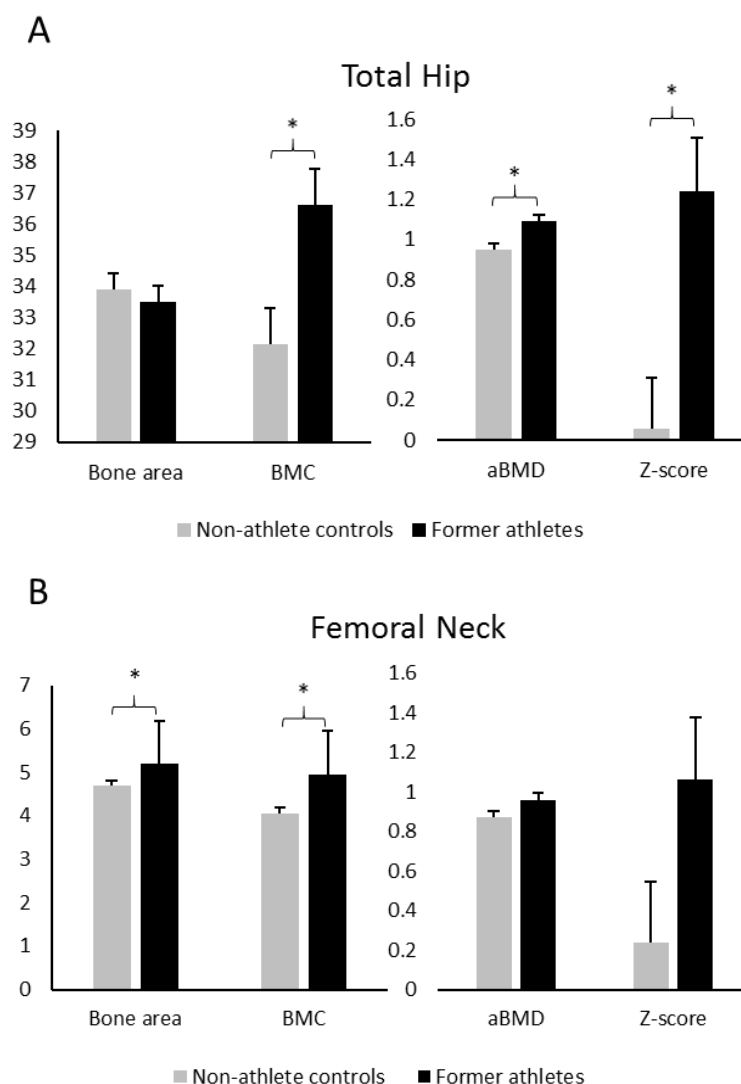


Figure 3.3, Panel A. Hip BMC, aBMD, and z-score least square means for female former athletes (black bar) and non-athlete controls (gray bar). Data are means adjusting for age, weight, height, and current physical activity. *Indicates a significant difference between groups ($p < 0.05$). **Panel B.** Femoral neck bone area, BMC, aBMD, and z-score least square means for female former athletes (black bar) and non-athlete controls (gray bar). Data are least square age-specific means adjusting for age, weight, height, and current physical activity. *Indicates a significant difference between groups ($p < 0.05$).

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CHAPTER 4

SPORTS PARTICIPATION IN HIGH SCHOOL AND COLLEGE LEADS TO HIGH
BONE DENSITY AND GREATER RATES OF BONE LOSS IN YOUNG MEN:
RESULTS FROM A POPULATION-BASED STUDY

Maggie Minett, M.S.,* Lee Weidauer, Ph.D.,* Howard E. Wey, Ph.D.,*[^] Teresa L.
Binkley, Ph.D.,* Tianna M. Beare,* Bonny L. Specker, Ph.D.*

*EA Martin Program in Human Nutrition, South Dakota State University, Brookings,
SD, USA; [^] College of Nursing, South Dakota State University, Brookings, SD, USA

ABSTRACT

Introduction: Estimated lifetime risk of an osteoporotic fracture in men over the age of 50 years is substantial and lifestyle factors such as physical activity may explain significant variation in bone mass and the bone loss associated with aging.

Methods: Men (n=253) aged 20-66 years were followed 7.5 years and factors that influence changes in means and rates of change in bone mass, density and size were investigated; in particular, seasons of sports participation during high school and college.

Results: Young men with the greatest participation in high school and college sports had higher femoral neck (5.2 ± 0.08 g and 5.3 ± 0.08 g vs. 5.04 ± 0.0 g and 5.02 ± 0.0 g; $p=0.02$) and hip BMC (48.1 ± 0.8 g vs. 45.3 ± 0.7 g; $p=0.01$) than men who participated in less sport seasons. However, men with higher participation in high school and college sports also had the greatest rates of bone loss (BMC, -0.14% and -0.41%; and aBMD, -0.08% and -0.35%, 7-12 and 13+ seasons of sport participation, respectively) early in life leading to similar hip BMC and aBMD as those did not participate in sports by their mid-fifties.

Conclusion: These findings support significant effects of sports participation on rates of change in bone mass and geometry in men throughout adulthood.

Keywords: bone QCT, general population studies, bone-muscle interactions, sports, osteoporosis

Introduction

While osteoporosis and osteoporosis-related fractures occur more frequently in women, the estimated lifetime risk of an osteoporotic fracture in men over the age of 50 years is substantial at 30% [1]. Additionally, mortality rates among fracture patients are higher in men than women [2]. It is therefore important to understand factors associated with bone gain and later bone loss in men. Heritability studies suggest that genetics factors can explain 50%-60% of the variability in bone mass [3, 4] but bone loading activities, particularly sports-related activities, have also been shown to influence bone acquisition [5-7]. Previous studies on the influence of sports participation have investigated peak bone mass and later bone loss in men [8-11]; however, little is known about the influence of sports participation on longitudinal changes in bone geometry.

A positive association between adult bone mass and past physical activity assessed retrospectively has been reported by some [6, 12], but not all previous studies [13]. Several longitudinal studies have either measured activity levels via recall or used sports participation or muscle strength as surrogates for activity to determine whether adult bone mass is associated with prior physical activity levels [9, 14-16]. A study by Tervo and Nordstrom found that reducing activity levels was associated with losses in trabecular bone, while benefits of increased activity early in life on cortical bone appeared to persist [16]. Nilsson et al. [14] and Lorentzon et al. [17] both reported results from the GOOD Study that showed that increased physical activity led to increased trabecular volumetric bone mineral density (vBMD) and increased cortical bone cross-sectional area. The majority of these longitudinal studies included young

men in a relatively narrow age range (~17-30 years old); however, some have demonstrated benefits much later in life [18, 19].

The South Dakota Rural Bone Health Study (SDRBHS) is a population-based longitudinal study of three distinct groups of individuals aged 20-66 years at baseline who were followed 7.5 years. The three groups included Hutterite and non-Hutterite rural and non-rural non-Hutterite (NH) populations. Both Hutterite and NH-rural populations live a similar rural farming lifestyle but with significant differences in social structure (Hutterites have a religion-based communal lifestyle); whereas, the NH-non-rural population never lived on a working farm and would be expected to have lower physical activity levels [20]. The initial rationale for enrollment of participants from these three distinct populations was to ensure a wide range in lifestyle factors that influence rates of bone loss with aging. Because Hutterites do not typically attend high school or college, the current analyses were limited to the NH populations only. The purpose of the current analysis was to determine whether sports participation in high school and college was associated with bone mass and rates of bone loss in men among the two non-Hutterite populations using both dual-energy x-ray absorptiometry (DXA) and peripheral quantitative computer tomography (pQCT) technologies.

Materials and Methods

Subjects

The SDRBHS is a population-based study of 1,271 adults aged 20 to 66 years who were enrolled between 2001 and 2004. Of the NH participants, 350 (184 males) were classified as rural and 336 (134 males) were classified as non-rural. Both rural and

non-rural populations were recruited from eight counties in South Dakota. To be considered rural the subject had to have spent $\geq 75\%$ of their life on a working farm while working < 1040 hours/year off the farm. In order to be considered non-rural the subject could never have spent time living on a working farm. Methods for recruiting and enrolling participants are described in greater detail elsewhere [20]. Written informed consent was obtained from all participants and the SDSU Institutional Review Board approved the protocol.

Procedures

Anthropometric, bone, body composition and grip strength measurements were obtained every 18 months and diet (24-hour) and physical activity (7-day) recalls were obtained quarterly for the first three years. Thereafter, food frequency questionnaires (FFQ) and activity recalls were obtained every 18 months. Height without shoes was measured in duplicate using a SECA stadiometer and recorded to the nearest 0.5 cm. Weight with light clothing was measured to the nearest 0.1 kg using a SECA (model 770) digital scale. Body composition and bone measurements of total body, hip, femoral neck (FN) and lumbar spine (LS) were measured using a Hologic QDR 4500A/Discovery (Bedford, MA). DXA and pQCT measurements (left radius using Norland-Stratec XCT2000, Pforzheim, Germany), including scan acquisition and analysis procedures, are detailed elsewhere [20]. CVs from duplicate scans on 9-15 adults following repositioning were $< 2\%$ for DXA BMC and bone area, and 0.5%, 1.2% and 0.5% for cortical vBMD, cortical thickness and total bone cross-sectional area (CSA) using pQCT at the 20% site, and 2.4% for trabecular density at the 4% distal site.

Quality control and quantification procedures outlined by Orwoll et al. were used to monitor and adjust DXA results for alterations in scanner performance [21].

A digital GRIP-D dynamometer (Takei Scientific Instruments Co., Ltd, Tokyo, Japan) was used to measure grip strength and was used as an indicator of overall fitness. Activity was measured as previously described [20] with the average daily percent of time spent in moderate-plus-vigorous activity (%MVPA) used as an indicator of current activity levels. The mean %MVPA obtained at 0, 3 and 6 months was used as a baseline (time=0) estimate; months 15, 18, and 21 for the 18-month estimate; and months 30, 33, and 36 for the 36-month estimate. Data from 54-, 72-, and 90-month visits were used for their respective estimates. In addition, questionnaires were administered to all participants at the end of the study to obtain sports participation information. The participants indicated the sport name, the number of years (seasons) of participation and whether it was JV/Varsity, club, or both for high school and college. The total sport-seasons per person of high school and college club and varsity sports participation was calculated by summing the total number of seasons of participation multiplied by each sport for each individual (for example: 1 season of participation in 4 different sports or 4 seasons of participation in one sport = 4 sport-seasons per person).

Statistical Analysis

Analyses were carried out using SAS statistical software (v 9.3, SAS Institute, Inc., Cary, NC). ANOVA was used to evaluate population differences in potential covariates, with Tukey adjustment for multiple comparisons. Linear mixed effects models were used to evaluate the association of sports participation with various bone outcomes. This approach allowed simultaneous evaluation of both cross-sectional

associations at baseline and longitudinal associations [22], and models random error among and within individuals, thereby taking into account repeated measures within an individual.

Rural and non-rural males were grouped together (n=318; 184 rural) and divided into groups based on sport-seasons of participation. Sport participation data were not available for all participants leaving a total sample size of 253 men (~80%). Sport group was defined by categorizing total sport-seasons per person into quartiles of 0, 1-6, 7-12 or 13+. The quartiles were divided as close as possible to 4 equal groups keeping all participants with similar sport-seasons of participation in the same quartile. For each bone outcome, the initial mixed model included fixed terms for population and sport groups, age, age², height, lean mass, and fat mass as baseline covariates and lean mass and fat mass as change covariates. Change covariates were calculated as the difference between the follow-up visit (18, 36, 54, 72, and 90-months) and baseline measurements. Coefficient estimates for change variables are interpreted as the mean change in bone outcome per one unit within-individual change in a covariate with adjustment for the follow-up time and other covariates in the model. The baseline bone measure is not the actual baseline measurement, but is the baseline bone measure estimated using the baseline predictors. This allows simultaneous evaluation of cross-sectional and longitudinal effects, as well as adjustment for baseline covariates. The model also included random terms for the intercept and slope. The age² term was included since most relationships with age were non-linear. Rates of change were investigated by including interaction terms that included time: age-by-time, group-by-time, sports-by-time, age-by-group-by-time, and age-by-sport-by-time. These interaction terms were

included to determine whether the rates of change differed by age (age-by-time), population group (group-by-time), sport group (sport-by-time), or whether the differences in the rates of change by age varied among population group (age-by-group-by-time) or sport group (age-by-sport-by-time).

In all analyses, baseline and change in %MVPA and grip strength were added individually to the final models after evaluation of interactions to determine whether they explained any of the differences that were observed. For illustrative purposes, marginal means and annual percent change in bone outcomes are graphed at different ages although the actual analysis was done on the rate of change as described above using age as a continuous variable. Denominator degrees of freedom were determined using the Satterthwaite approximation. Data are means \pm standard deviations unless otherwise noted.

Results

Comparison of baseline characteristics by sport participation indicated that men who participated in 13+ sport-seasons were the youngest of all groups and men who competed in 7+ years were taller and had greater grip strength than men with no sports participation (Table 4.1).

Cross-sectional associations

Table 4.2 summarizes the marginal means for bone measurements by sports participation. FN and hip BMC were greater in men with 7-12 or 13+ sport-seasons compared to either 0 or 1-6 sport-seasons of participation (Figure 4.1; Hip and FN outcomes were similar, both $p \leq 0.02$). Spine BMC and FN, hip and spine aBMD were

greater with more years of sports participation in younger men, but the differences by sport participation were less apparent in older men (Figures 4.1 & 4.2; sport-by-age interaction, all $p \leq 0.01$). A similar finding was observed for trabecular vBMD: trabecular vBMD of men with 7-12 sport-seasons of participation was initially higher than the men with 6 or less sport-seasons of participation but was lower in older ages while men with no sports participation had similar trabecular vBMD across all ages (Figure 4.3; sport-by-age interaction $p < 0.01$). For CSA, cortical area, and pSSI, the relationship between sport group and bone outcome varied by age and this relationship was non-linear (Figure 4.3; age²-by-sport interaction, all $p \leq 0.02$). Sports participation did not influence hip or spine bone area or cortical vBMD or thickness.

Longitudinal associations

There were no significant differences in the rates of change of hip, FN or spine area or FN and spine BMC and spine aBMD for men who did or did not participate in sports (Table 4.2, Figures 4.1 & 4.2). Men with more seasons of sports participation had the greatest rates of loss in hip BMC and aBMD prior to age 60 (Figure 4.1). The association between the rate of bone loss in FN aBMD and seasons of sport participation varied by age, with the men with 13+ sport-seasons of participation having the greatest loss at younger ages, yet by the mid-fifties, the rates of loss were approximately the same among all men regardless of the seasons of sports participation (data not shown; similar to hip aBMD). The rate of change in cortical vBMD tended to vary by sports participation with annual percent change of 0.09%, 0.17%, 0.12% and 0.18% for 0, 1-6, 7-12 and 13+ sport-seasons of participation (sport-by-time interaction, $p = 0.06$).

Discussion

Findings regarding sport participation are of interest for several reasons. Sports participation and physical activity are an important mechanism in the accrual and maintenance of bone health. This is supported by our finding that total hip and FN BMC was greater in men who participated in 7-12 or 13+ sport-seasons compared to those who participated in 6 sport-seasons or less or no sports in high school or college. Cross-sectional area, cortical area, and pSSI were greater in the 7+ sport-seasons compared to the non-sport group although this relationship varied by age and was not linear.

A study by Nilsson et al. that found a 16% greater tibial and radial CSA in the soccer playing group than the nonathletic group [23]. Additionally, Nilsson et al. demonstrated that the type of physical activity may be just as beneficial when it comes to the osteogenic effect of sport participation on bone as the soccer playing group had greater FN and LS aBMD, tibial CSA, and trabecular bone volume fraction than the resistance exercise counterparts [23]. However, the soccer player group had a significantly longer history of sport training than the resistance training group (15 years vs. 5 years, respectively) which may demonstrate an effect of bone mass accrual before puberty. Our finding of a greater trabecular vBMD at younger ages in men who participated in 7-12 sport-season of participation than men with 1-6 sport-seasons is consistent with a study by Lorentzon et al. who reported higher trabecular vBMD in men who were currently physically active and who started their training before 13 years of age [17].

Studies that have investigated rates of change in bone measures among men have reported inconsistent findings [24]. Although hip BMC and FN and hip aBMD (at

younger ages) was higher in the 7+ sport-seasons groups compared to the two groups with less sports participation, their rates of bone loss were higher especially at the younger ages for aBMD. Increased rates of bone loss at the hip early in life among men who participated in 7+ sport-seasons would explain similarities in FN and hip aBMD regardless of sports participation by the mid-fifties. Our findings are consistent with Tervo et al. who followed athletes and non-athletes aged 17 years for 12 years and found that former athletes had higher aBMD than controls at every visit except the 12-year visit [8]. Currently active athletes maintained higher aBMD at all visits indicating that aBMD adapts to present activity levels, and that high activity levels early in life may not prevent osteoporosis in later years if activity levels are not maintained [8]. However, studies of former male soccer players have demonstrated maintenance of aBMD after retirement. Uzunca et al. reported greater aBMD values at the spine and FN in former male soccer players (average age of 52) than non-athletic controls regardless of current physical activity levels [25] while a study from Sweden showed leg BMD remained different between controls and former soccer players 30 years after retirement [26]. It may be worthwhile to determine the type of previous and current physical activity as various sports have different osteogenic effects, and one sport or type of loading may be more beneficial than another in maintaining bone mass after retirement.

In studies of early bone loss in males that are not specifically investigating the effect of sports participation, there appears to be a similar trend in early bone loss [9, 27-29]. Nordstrom et al. reported early losses in hip aBMD, but no changes in LS aBMD, in males aged 17 years at baseline and followed for 7.5 years [9]. They estimated that 25% of the aBMD gained at the hip in early adulthood would be lost by age 50 regardless of

physical activity patterns. The Swedish GOOD study also found losses over a 5-year period in hip aBMD in young men aged 19-24 years [28], while the Tromso Study did not find changes in distal radius aBMD at 25-29 years of age but did find significant loss in the 35-39 year age group [29]. We previously reported significant loss in femoral neck BMC and aBMD and trabecular vBMD among men in their 20's that was greater among non-rural men than Hutterites and rural men [27]. In contrast, a study by Khosla and coworkers [30] found significant rates of gain in hip and radius aBMD in 22-39 year olds and no change in hip aBMD in 60-90 year olds over a 4-year period. Our results are consistent with a beneficial effect of early activity on bone in young adults that diminishes with time.

Prior to adjusting for covariates, there were greater DXA and pQCT bone measures with increasing years of sports participation. These results are consistent with findings from other investigators who reported increased bone size and strength with increased activity [17, 31, 32]. Warden et al. demonstrated greater CSA and cortical area in the humerus of the throwing arm vs. non-throwing arm of baseball players and this side-to-side difference was different from controls indicating an effect of bone adaptation to muscle loading. This difference in the loaded vs. non-loaded arm remained until 40+ years after retirement [33]. However, not all investigators determined the independent effect of activity on bone controlling for muscle mass and size. Activity is thought to influence bone through increased loading from either exercise itself or from the muscle forces placed on the skeleton. Since differences among the sports groups in several bone measures persisted after controlling for differences in muscle mass and strength, it is likely that the external loads placed on the skeleton through the activities

contributed to the higher bone measures. Others found activity in young adult men was associated with increased FN and LS aBMD as well as increased cross-sectional bone area [17]; these measures were higher in subjects who started training before age 13 compared to subjects who starting training later. Unfortunately, we did not determine the age that training started, but men who participate in sports throughout their high school and college years are likely to have participated in sports prior to puberty.

There are several unique aspects of the current study. First, this study is a population-based study that was conducted in eight counties in eastern South Dakota and includes a wide age-range of participants. Second, we obtained detailed dietary and activity information on a quarterly basis during the first 3 years of the study. Third, we obtained bone measures using pQCT in addition to DXA, which allowed us to obtain information on changes in bone geometry with aging.

In addition to these strengths, there are limitations. As mentioned, we did not have information on sports participation prior to puberty and can only speculate that men who participated in high school and college sports participated in sports prior to puberty. However, many men who did not participate in high school or college sports could have participated in sports prior to puberty. Additionally, we do not have information on the length of the seasons of sport participation or the type of sport the participants were involved in which would provide valuable insight in the potential long-term osteogenic effect of certain sports. pQCT measurements were made only at the radius and did not include tibial measures. It is possible that tibia measures may have differed from those observed at the radius due to the weight-bearing nature of the bone.

In summary, young men who participated in high school or college sports had greater hip and FN BMC and bone size than men who did not participate in sports; however, due to their greater rates of bone loss, these differences were no longer apparent by the mid-fifties. These results indicate that there is a long-term benefit of increased activity early in life, but this activity must be maintained in later years if it is to prevent the development of osteoporosis at older ages.

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TABLES

Table 4.1. Baseline Characteristics by Sport-seasons per Person of Participation in High School and College Club and Varsity Sports

	0 Seasons (N=57)	1-6 Seasons (N=68)	7-12 Seasons (N=68)	13+ Seasons (N=60)	P Value
Range in Sport-season per Person	0	1-6	7-12	13-38	
Non-Rural/Rural (N)	19/38	26/42	33/35	28/32	NS
Age (y)	48.4 (11.7) ^a	46.4 (11.9) ^b	46.3 (9.9) ^c	41.0(12.6) ^{abc}	<0.01
Height (cm)	176.0 (6.8) ^{ab}	177.2 (6.6)	180.0 (6.5) ^b	180.0 (8.9) ^a	<0.01
Weight (kg)	94.3 (23.1)	90.5 (12.3)	94.1 (18.4)	93.7 (15.6)	NS
Lean Mass (kg)	65.4 (9.5)	66.1 (6.7)	68.4 (8.9)	69.4 (8.6)	0.04
Fat Mass (kg)	25.4 (11.8)	22.4 (7.4)	22.7 (8.9)	22.0 (9.5)	NS
% MVPA	19.6 (9.5)	19.7 (10.7)	20.2 (10.2)	17.7 (8.6)	NS
Grip Strength (kg)	47.5 (7.8) ^{ab}	49.4 (9.6) ^a	52.2 (8.1) ^b	53.7 (8.2) ^a	<0.001
Dietary Calcium (mg/d)	1205 (624)	1076 (436)	1048 (610)	1201 (406)	NS

Data are unadjusted means (\pm SD). Data with similar superscripts are significantly different (Tukey HSD $p<0.05$). MVPA=moderate + vigorous physical activity; NS = not significant

Table 4.2. Bone Measures by Sport-seasons per Person in High School and College Club and Varsity Sports

	Sport-Seasons of Club & Varsity Sports ¹				Cross-Sectional		Rate-of-Change	
	0 Seasons (N=57)	1-6 Seasons (N=68)	7-12 Seasons (N=68)	13+ Seasons (N=60)	P Value	Age-by- Sport	P Value	Age-by- Sport
<u>Femoral Neck</u>								
BMC (g)	5.04 ± 0.08 ^{ab}	5.02 ± 0.07 ^{cd}	5.27 ± 0.08 ^{ac}	5.31 ± 0.08 ^{bd}	0.02	NS	NS	NS
Area (cm ²)	5.88 ± 0.04 ^a	5.75 ± 0.04 ^{ab}	5.82 ± 0.04	5.87 ± 0.05 ^b	NS	NS	NS	NS
aBMD (g/cm ²)	0.843 ± 0.014 ^{ab}	0.862 ± 0.012 ^c	0.897 ± 0.013 ^{ac}	0.891 ± 0.014 ^b	^	<0.01	^	<0.01
<u>Total Hip</u>								
BMC (g)	45.6 ± 0.8	45.3 ± 0.7 ^a	48.1 ± 0.8 ^a	48.1 ± 0.9	0.01	NS	^	0.05
Area (cm ²)	45.0 ± 0.5	44.2 ± 0.4	44.7 ± 0.5	44.5 ± 0.5	NS	NS	NS	NS
aBMD (g/cm ²)	1.014 ± 0.015 ^{ab}	1.026 ± 0.013 ^{cd}	1.076 ± 0.014 ^{ac}	1.079 ± 0.015 ^{bd}	^	0.01	^	<0.01
<u>Spine</u>								
BMC (g)	72.9 ± 1.8 ^a	74.9 ± 1.5	79.5 ± 1.7 ^a	78.0 ± 1.8	^	<0.01	NS	NS
Area (cm ²)	69.1 ± 0.6 ^a	70.0 ± 0.5	71.4 ± 0.6 ^a	70.2 ± 0.6	NS	NS	NS	NS
aBMD (g/cm ²)	1.050 ± 0.020	1.069 ± 0.017	1.108 ± 0.019	1.107 ± 0.020	^	<0.01	NS	NS
<u>20% Distal Radius</u>								
CSA (mm ²)	153 ± 3 ^{ab}	158 ± 2	161 ± 3 ^a	161 ± 3 ^b	^	0.02 ²	NS	NS
Cort Thickness (mm)	2.96 ± 0.04	2.97 ± 0.03	3.00 ± 0.04	3.00 ± 0.04	NS	NS	NS	NS
Cort Area (mm ²)	102 ± 1 ^a	104 ± 1	106 ± 1 ^a	105 ± 1	^	0.01 ²	NS	NS
Cort vBMD (mg/cm ³)	1192 ± 3	1189 ± 3	1191 ± 3	1186 ± 3	NS	NS	0.06	NS
pSSI (mm ³)	387 ± 9 ^a	398 ± 8	412 ± 9 ^a	405 ± 9	^	0.02 ²	NS	NS
<u>4% Distal Radius</u>								
Trab vBMD (mg/cm ³)	225 ± 4	225 ± 4 ^{ab}	236 ± 4 ^a	224 ± 4 ^b	^	<0.01	NS	NS

Data are marginal means (±SE). Data with similar superscripts are significantly different after adjusting for multiple comparisons (Tukey HSD at p<0.05). ^ = included in higher order interaction. ¹Only significance for main effect of sport or age-by-sport interaction are shown. In addition to the above terms, other covariates included baseline age, age², height, lean mass, and population; changes in lean and fat mass; time, age*population, age²*population, age*time, age²*time, time*population, age*time*population, and age²*time*population. ²Age²-by-population was significant. BMC = bone mineral content; aBMD = areal bone mineral density; CSA = cross-sectional area; Cort = cortical; vBMD = volumetric bone mineral density; Trab = trabecular; pSSI = polar stress strain index; NS = not significant.

FIGURES

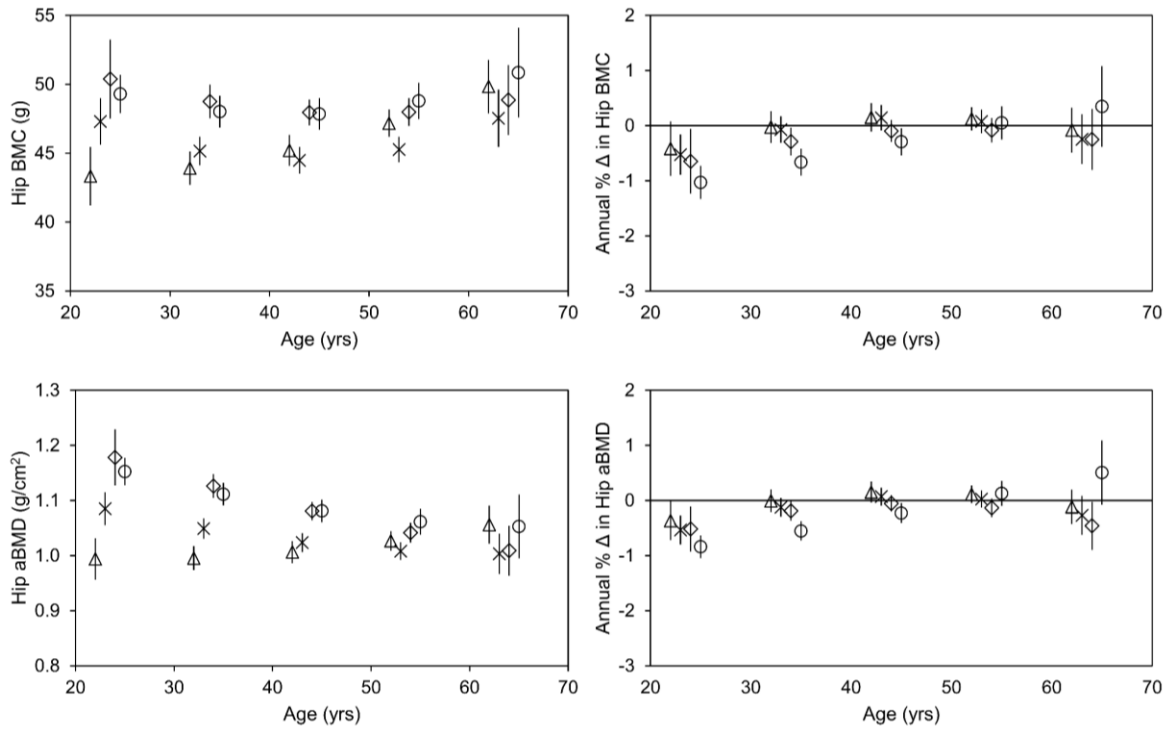


Figure 4.1. Hip BMC and aBMD marginal means and annual percent change by sport-seasons of participation in varsity and club sports group (Δ =0 seasons; \times =1-6 seasons; \diamond =7-12 seasons; \circ =13+ seasons).

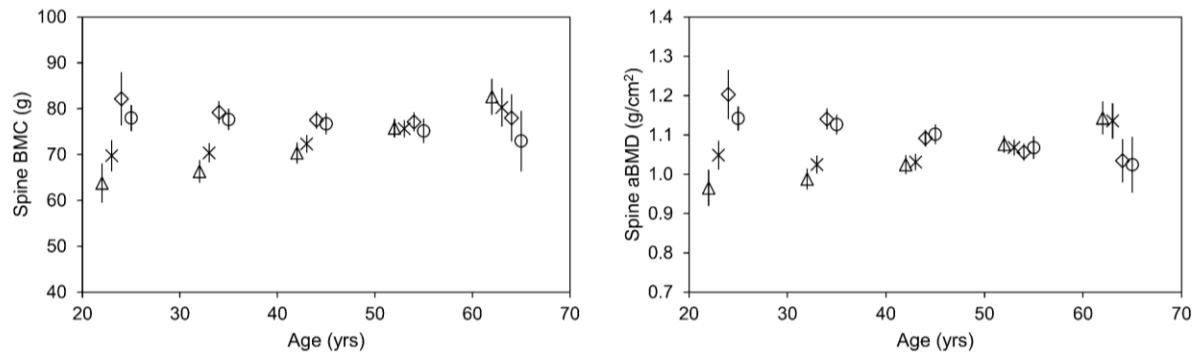


Figure 4.2. Spine BMC and aBMD marginal means by sport-seasons of participation in varsity and club sports (Δ =0 seasons; \times =1-6 seasons; \diamond =7-12 seasons; O =13+ seasons).

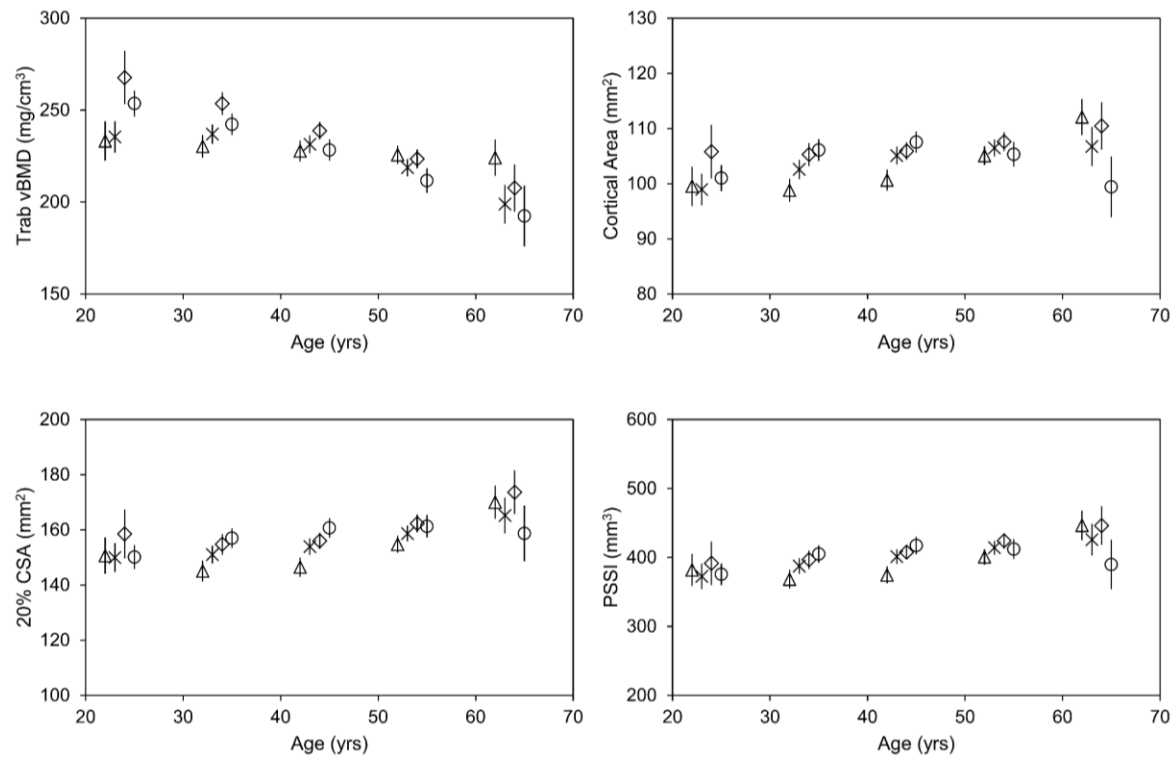


Figure 4.3. Trabecular vBMD, cortical area, CSA, and pSSI marginal means by sport-seasons of participation in varsity and club sports group (Δ =0 seasons; \times =1-6 seasons; \diamond =7-12 seasons; O =13+ seasons).

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CHAPTER 5

DISCUSSION AND OVERALL CONCLUSION

Mechanical loading – or physical activity - is essential in bone accrual and maintenance through the process of bone remodeling. One convenient avenue to encourage physical activity is participation in sports. Findings regarding sport participation are of interest for several reasons. Sports have been shown to be effective in eliciting more favorable material and geometric bone properties in athletes compared to non-athletes. Furthermore, the favorable effects of sport participation on bone parameters appear to remain for years beyond retirement from sport. Thus, sport participation continued through high school and college can be viewed as valuable in two ways. It can perpetuate the benefits of physical activity during adolescence into young adulthood and also, participation in sports may be a convenient mode to encourage appropriate physical activity – and bone maintenance – throughout adulthood in hopes to mediate age-related bone loss.

In the longitudinal study of current soccer athletes presented in Chapter 2, we demonstrated that collegiate soccer participation had a positive effect on DXA measured total hip and femoral neck aBMD and that these aBMD measures did not change over the competitive season in the soccer players even though the group lost lean mass. Unique in this study is the measure of pQCT throughout the different stages of the season. Although we did not see changes in aBMD, the soccer player group increased bone size during the competitive season and increased cortical thickness over the spring training season. This increase in bone size and thickness suggests an adaptation to the increased loading

experienced during the competitive season and subsequent bone remodeling (increase in thickness) when rest is sufficient to adapt the geometrical bone properties to the loads. Important to note, the changes in bone size and cortical thickness differed on the amount of playing time as starters had a significant increases in these measures while non-starters did not. The loads or the frequency of the load on the bone need to be great enough to elicit change; therefore, the non-starter group may not have met this threshold. This study demonstrated the positive influences of sport participation on bone; however, it is unknown the extent that these influences remain after participation in sport is ended. To determine this, we conducted a study to compare aBMD measures between former collegiate athletes and non-athletic controls.

Chapter 3 describes a study of hip and spine bone density in former male and female athletes at varying years beyond their sport career compared to age- and sex-matched non-athlete controls. In the former male football players, spine aBMD was the only measure that was higher than controls after 15 years of retirement which could be a result of the type of loading within the sport. The fact that we did not see a difference between former male football athletes and controls in hip aBMD could be due to the greater rates of aBMD loss seen in former athletes that would result in similar measures by 15 years post-career. The female former soccer players had higher spine and hip aBMD and femoral neck BMC than controls after 6 years of retirement which demonstrates a short-term positive effect of collegiate sport participation. Through the cross-sectional evaluation of aBMD in these male and female former athletes, it appears that collegiate sports participation had a beneficial effect on aBMD that is attenuated as the years from sport cessation increase. The two sports demonstrate two types of loading

patterns; the high-impact and magnitude loading of football vs. odd-impact loading of soccer. It is possible that the effect of the sport on bone can be sport-specific and that certain sports could have a greater effect on aBMD than others. Perhaps not only the length of time spent active in sports, but also, the type of sport needs to be taken into consideration when assessing the link between sport participation beyond adolescence and later aBMD measures. With the cross-sectional nature of this study, we were unable to calculate rates of change in bone measures to determine the annual rate of loss in athletes which may provide a more detailed assessment of the effect of detraining on bone. However, this issue was addressed in our population-based study presented in Chapter 4.

In the population-based study, we evaluated DXA and pQCT measures of individuals with no high school or college sport participation with those who had 1-6, 7-12, or 13+ seasons of participation. The mean ages of the groups ranged from 40 to 50 years old which would approximate about 15-30 years of retirement from sport. In all of the results, 13+ seasons of sport participation was not more effective (and in some cases, less effective) in maintaining bone measures than the 7-12 season of sport group indicating a possible threshold for sport participation during young adulthood. Overall, participation in 7 or more seasons of sport appeared to be beneficial in maintaining higher hip BMC and FN and hip aBMD compared to those who participated in less seasons of sport although aBMD varied by age. The groups with the highest sport participation also had the greatest rates of bone density loss (at younger ages) which explains similar aBMD regardless of sports participation by the mid-fifties. Since bone strength is a combination of both material and geometric properties, aBMD measures alone do not

provide a complete picture of how sports participation can influence bone strength long-term and the pQCT results of this study are a valuable tool in understanding this relationship. The radial pQCT measures provide a unique insight into bone geometric changes related to previous sport participation. Of great interest is that bone size (CSA) and strength (pSSI) was greater in the 7-12 sport participation group compared to the non-sport group although this relationship varied by age. Unlike aBMD measures, there were not significant rates of change in radial pQCT outcome measures. It is unknown whether or not this is related to the non-weight bearing nature of this bone. pQCT measures of the tibia (in addition the radius) may provide more information in the long-term effect of sport participation due to the different loading patterns of these bones. Future studies could add to the knowledge gain by this study by incorporating the age that sport training started and the types of sport since differences in several bone measures between groups persisted after controlling for muscle mass and strength. It is probable that the higher bone measures are a result of the loads placed on the bone during physical activity. Examining the type of sport these former athletes participated in would provide greater knowledge on the long-term osteogenic effect, if any, of various sports.

In conclusion, the studies presented indicate a positive effect of current and past high school and collegiate sport participation on aBMD and bone size compared to non-athlete controls and that these positive effects can be seen up to 10-15 years after retirement from sport. Albeit, further research is needed to define types of sport, necessary loads or loading patterns and frequency to elicit a positive bone response that is fit for individuals throughout life. Perhaps, the question should not only be how long the individual participated in athletics throughout adolescence and young adulthood

(certainly these are proven to be beneficial), but rather, what type of exercise is best for an individual to continue throughout life to maintain density and favorable geometric properties.